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FINAL REPORT, CONTRACT FAA ARDS-437

DEVELOPMENT OF MODEL 3500 ARRESTING GEAR AND CONTINUED DEVELOPMENT OF SPRING HOOK FOR COMMERCIAL AIRCRAFT

M-788
PART 1
January 1963

Prepared for

FEDERAL AVIATION AGENCY
SYSTEMS RESEARCH AND DEVELOPMENT SERVICE

By

ALL AMERICAN ENGINEERING COMPANY
WILMINGTON, DELAWARE

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This report has been prepared by All American Engineering Company for the Systems Research and Development Service, Federal Aviation Agency, under Contract No. FAA ARDS-437. The contents of this report reflect the views of the contractor, who is responsible for the facts and the accuracy of the data presented herein, and do not necessarily reflect the official views or policy of the FAA.

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DEVELOPMENT OF MODEL 3500 ARRESTING GEAR AND CONTINUED DEVELOPMENT OF SPRING HOOK FOR COMMERCIAL AIRCRAFT, W. R. Schlegel, January, 1963
2 volumes, 240 pages, 65 illustrations, Final Report

ABSTRACT

This report summarizes the work involved in the development of the Model 3500 Arresting Gear for emergency use with large commercial aircraft. The utilization of a large gas turbine launcher, dead load design to simulate aircraft mass, the continued development of the Sheaffer Spring Hook, and actual aircraft testing are discussed.

Data and results from 55 on-center and off-center dead load engagements at Sussex County Airport, Georgetown, Delaware and the ensuing 41 taxi-in and fly-in arrestments at the National Aviation Facility Experimental Center, Atlantic City, New Jersey, are presented.

The aircraft used for testing were the Boeing 720-027 and the Convair C-131B.

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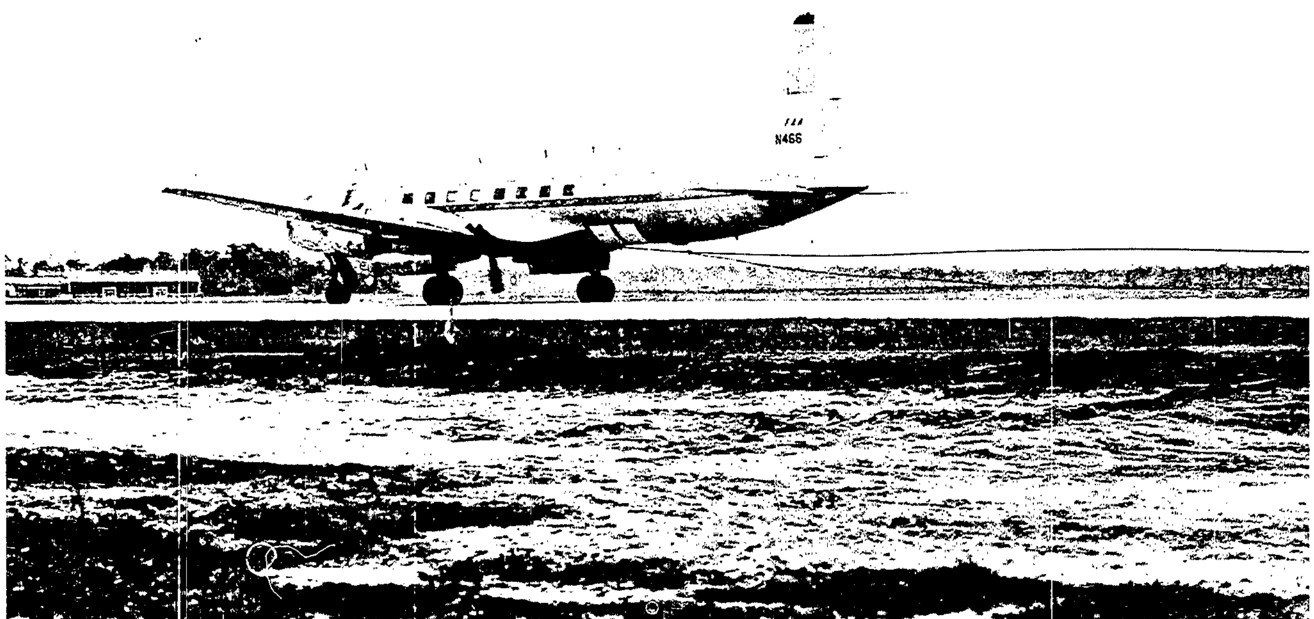


Frontispiece. Arrestment of C-131B by AAE Model 3500 Arresting Gear

I. INTRODUCTION

The design and development project covered by this report was conducted by All American Engineering Company, Wilmington, Delaware, under contract with the Aviation Research and Development Service of the Federal Aviation Agency. The work of the project is specified in the FAA ARDS-437 contract plus Amendments 1 through 6.

Aircraft operation statistics show that approximately 18% of all aircraft accidents are during the take-off phase and about 47% during landing. Some portion of this 65% of all aircraft accidents can be prevented by use of an adequate arresting gear either in the take-off abort, wherein the aircraft is heavy and fast at a critical point on the runway, or while in a landing phase, usually lighter and slower.

The Model 3500 Arresting Gear represents the current state of art of building a water squeezer type emergency aircraft arresting gear. Engineering development knowledge of water squeezers has been accumulated from development of arresting gears for use by the U. S. Navy, U. S. Air Force, U. S. Marines, and the Royal Canadian Air Force, including 12 designs such as the Model 340, the E-14, E-14-1, and the BAK 6/F-27A. Most of these designs have been emergency arresting systems to take care of the occasional mishap, either in landing or take-off. Some designs have originated from the concept of Marine expeditionary or fast recycle use, with every landing being an arrested landing. The Model 3500 concept is for emergency use with no provision for fast recycling, thus keeping the design as simple as possible with low maintenance effort and skill required.

Contract ARDS-437 provided for the design and development of a water squeezer type arresting gear for civil transport aircraft to be tested by dead load engagements. The original contract is dated 1 September 1961. Amendments 1 through 5 increased the scope of work to include:

(1) Additional on-center dead load engagements.

(2) Manufacture of a second arresting gear and installation at a designated airport.

(3) Off-center dead load engagements.

(4) Design and manufacture of aircraft spring hooks.

(5) Aircraft tests.

The final aircraft tests were completed on 9 November 1962.

II. DESCRIPTION OF MODEL 3500 ARRESTING GEAR

The Model 3500 Arresting Gear is a "water-squeezer" type energy absorber designed in accordance with specifications as defined in Contract ARDS-437. These specifications are:

Type energy absorber - Water squeezer

Aircraft weight range - 50,000 to 350,000 pounds

Maximum engaging velocity - 130 knots

Maximum aircraft deceleration - 1g

Aircraft runout - less than 2000 feet

Method of engagement - Tail hook

Method of retrieve - Vehicle tow

Arresting gear cable size - 1-1/2-inch-diameter

Installation - Permanent type

A "water-squeezer" is a linear hydraulic energy absorber in which a loosely fitting piston attached to a wire rope is pulled through a tube filled with fluid. In order to program the retarding force so that the hook load is sustained during the deceleration cycle, the hydraulic portion of the arresting tube is tapered down in steps. Figure 1 illustrates the piston being pulled through the tube (step tapering exaggerated).

In order to further define the important arresting gear design parameters, the following additional specifications were imposed by All American Engineering Company:

Maximum runout - 1750 feet (new cable)

(approximately 1770 feet after stretch)

Arresting cable type - 6 × 19 class, independent wire rope core

Breaking strength - 228,000 pounds minimum

Retrieve rope - 1-inch-diameter premium grade Nylon

Off-center engaging distance - 20 feet (design), 60 feet (tested)

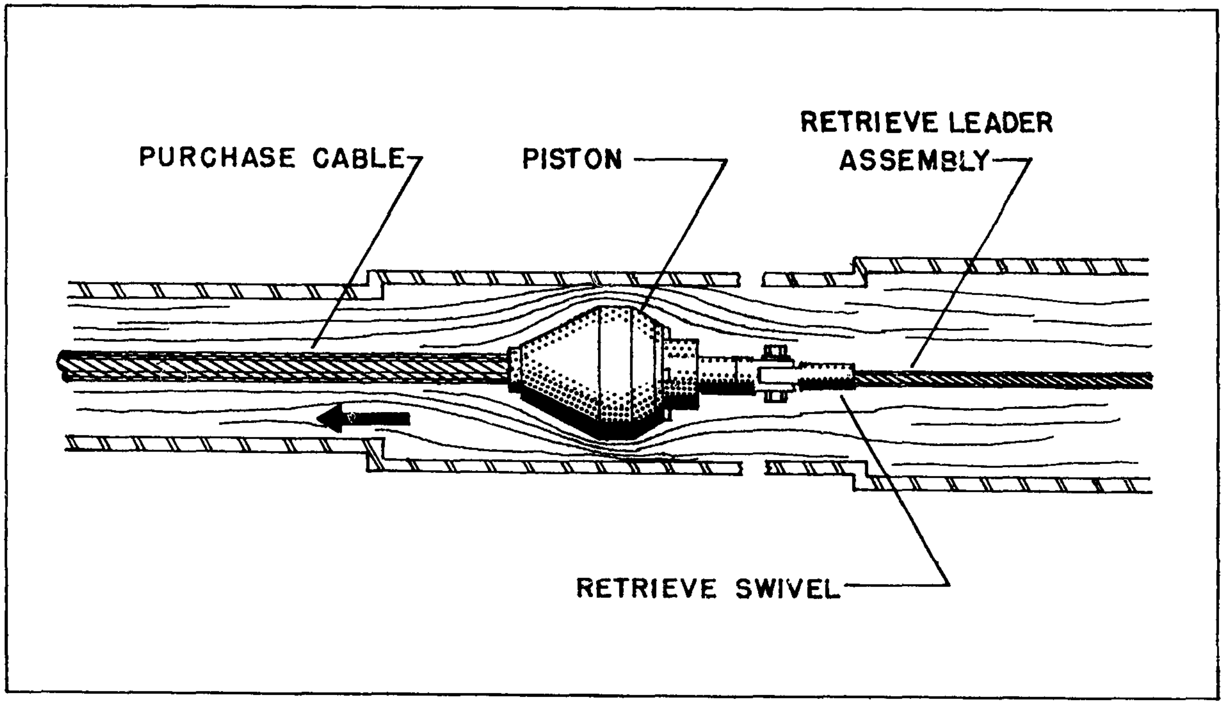


Figure 1 Schematic of Piston in Hydraulic Arresting Tube

Piston diameter - 7-3/16 inches

Hydraulic arresting tube - 1/2-inch wall thickness

7-1/4-inch minimum inside diameter

9-inch maximum inside diameter

920-foot length

Hydraulic working pressure - 3500 psi (at arresting end)

Dry tube - 1/4-inch wall thickness

8-inch inside diameter × 590 feet long

Arresting gear length - 1620 feet

Span between sheaves - 400 feet

Figure 2 shows a typical installation layout of the Model 3500 arresting gear. It should be noted that only the deck sheaves and pre-tensioning cable are above ground level.

To best describe the function of the Model 3500 arresting gear, a typical arresting and retrieve cycle with aircraft is described.

As the aircraft approaches the arresting gear, the tail hook is dropped. After the main landing gear passes over the deck pendant, the aircraft tail hook engages the pendant, which is connected to the purchase cables through a swivel and link cable. The purchase cables, which terminate at conical pistons, are pulled through the tubes and around deck sheaves at ground level. The initial 600 feet of piston travel is through an empty or dry tube.

The purpose of the dry tube portion of the arresting engine is to delay the major hydraulic retarding forces until the dynamic cable loads are dissipated, thus providing a more efficient energy absorption cycle. After moving about 600 feet, the piston enters the hydraulic portion of the arresting tube and decelerates due to the hydraulic drag forces incurred. The aircraft is brought to a smooth but rapid stop. A one-inch nylon rope attached to the rear of the piston is pulled from its stowed (faked) position in a box in the retrieve pit. Figure 3 shows the faking

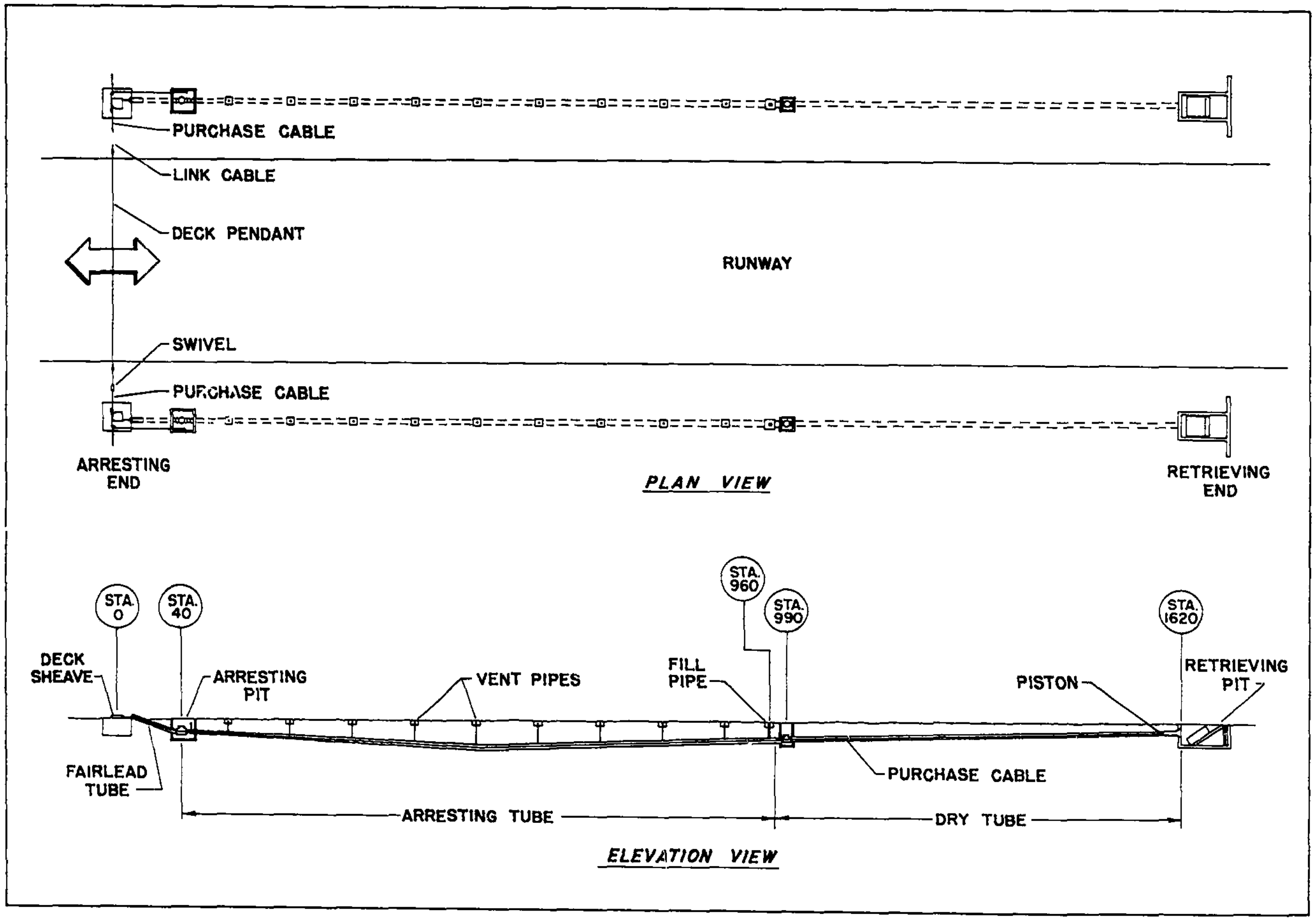


Figure 2 Typical Plan and Elevation View of Model 3500 Arresting Gear Installation

box stored in the retrieve pit prior to an arrestment. To support the deck pendant for arresting hook engagement, some accessory equipment is generally required, such as a suitable support. To keep the deck pendant taut for automatic lateral pendant positioning and minimum catenary between pendant supports, a manual preset pre-tensioning system is utilized at each side of the runway. Upon engagement the arresting hook impact generates a longitudinal tension wave in the cable which causes the pre-tension to be released by failing a shear pin at each side of the runway. The pre-tension level on the Model 3500 is 8000 pounds with a 12,000-pound shear failure value. Figure 4 shows the lateral portion of the pre-tension system and the connection of the pre-tension cable to the arresting cable through a cable clamp and shear pin. The pre-tension system is a double reeved 1/2-inch-diameter cable system with a 1-1/2-inch-diameter nylon rope to act as a spring at one end. The other end is attached to a hand operated hoist in the arresting pit at Station 40. The slack cable at the back of the hoist is stored on a shock cord powered take-up reel. Figure 5 shows the pre-tensioning mechanism in the Station 40 pit.

After completing the arrestment and disconnecting the cable from the aircraft, a vehicle pulls the center of the deck pendant down the runway centerline in a loop past the deck sheave position in order to reduce the retrieve load. Concurrently, retrieve ropes are reeved through the snatch blocks at the end of the retrieve pit in preparation for vehicle retrieve.

A pre-tension clamp on either side of the runway is connected to the pre-tension cable by insertion of a new shear pin (AN5 bolt). The retrieve rope on the opposite side of the runway is connected to a vehicle and pulled until the cable system is taut against the shear pin previously connected. Subsequently, the other shear pin is inserted and the deck pendant tensioned on both sides while the retrieve vehicle prepares to retrieve the second side.

After both pistons are returned to battery position, another set of faking boxes, with rope previously prepared, are connected and set in position in the

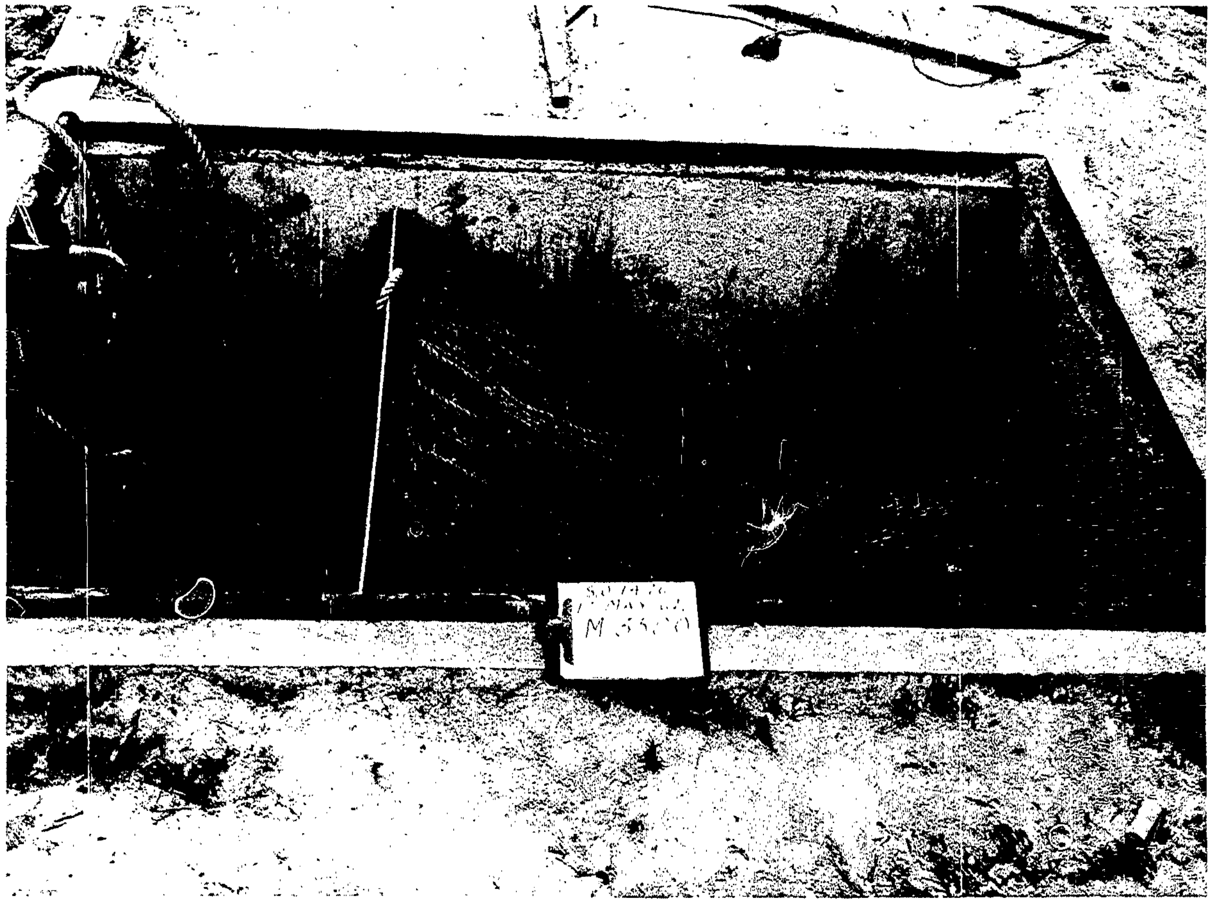


Figure 3 Faking Box Containing Retrieve Rope in Retrieve Pit Prior to an Arrestment

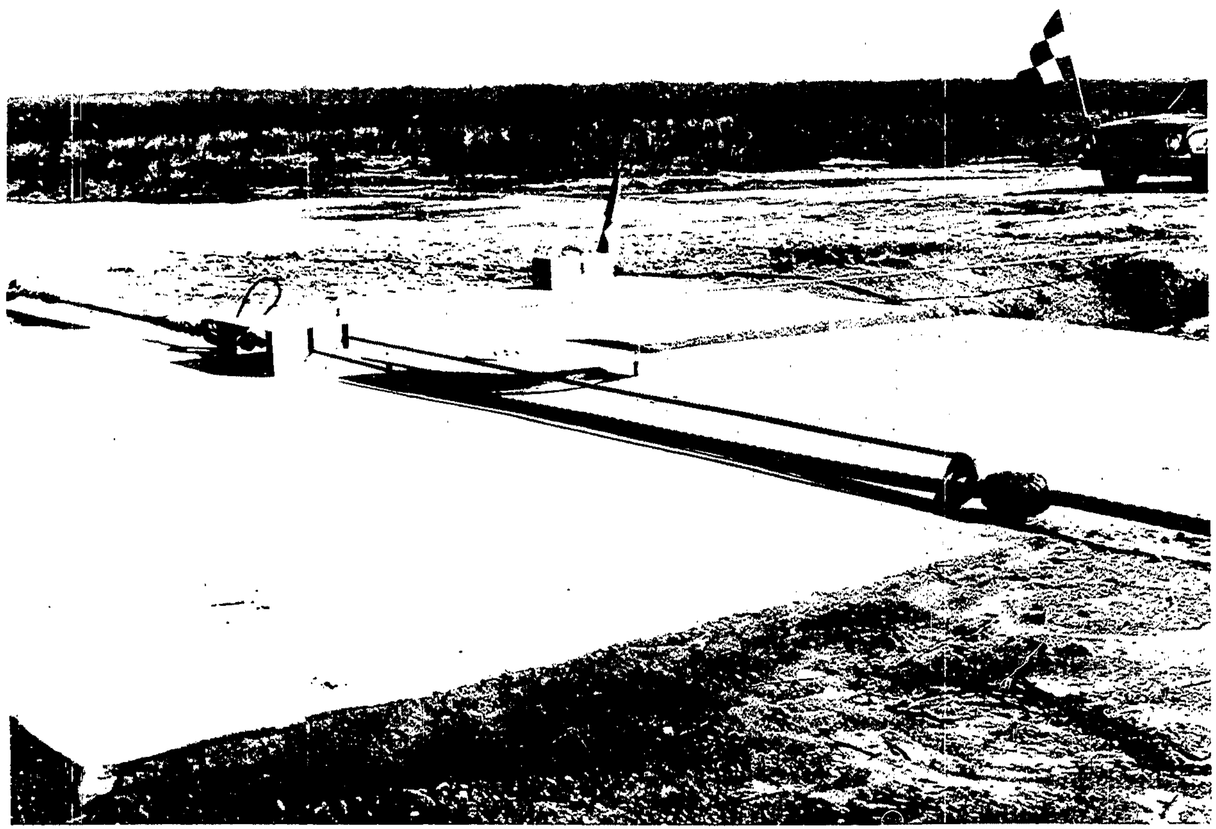


Figure 4 Portion of Pre-tension System Located Above Ground Level, Including Cable Clamps, Shear Pin, Pre-tension Cable, Nylon Spring, and Pre-tension Sheave Housing

Figure 5 Pre-tensioning Mechanism Located in Station 40 Pit Including Fairlead Sheaves, Hoist, and Slack Cable Drum

retrieve pits.

The vent caps (see figure 2) are removed and the water level re-established in both tubes at the fill pipes at Station 960. The caps are replaced, and the gear is ready for another arrestment.

Each tube of the Model 3500 Arresting Gear holds approximately 2000 gallons of fluid at the proper filling level. The fluid loss during an arrest varies with the engaging energy and should be re-established according to the recommended dip stick height. The average water loss is about 150 to 200 gallons per tube.

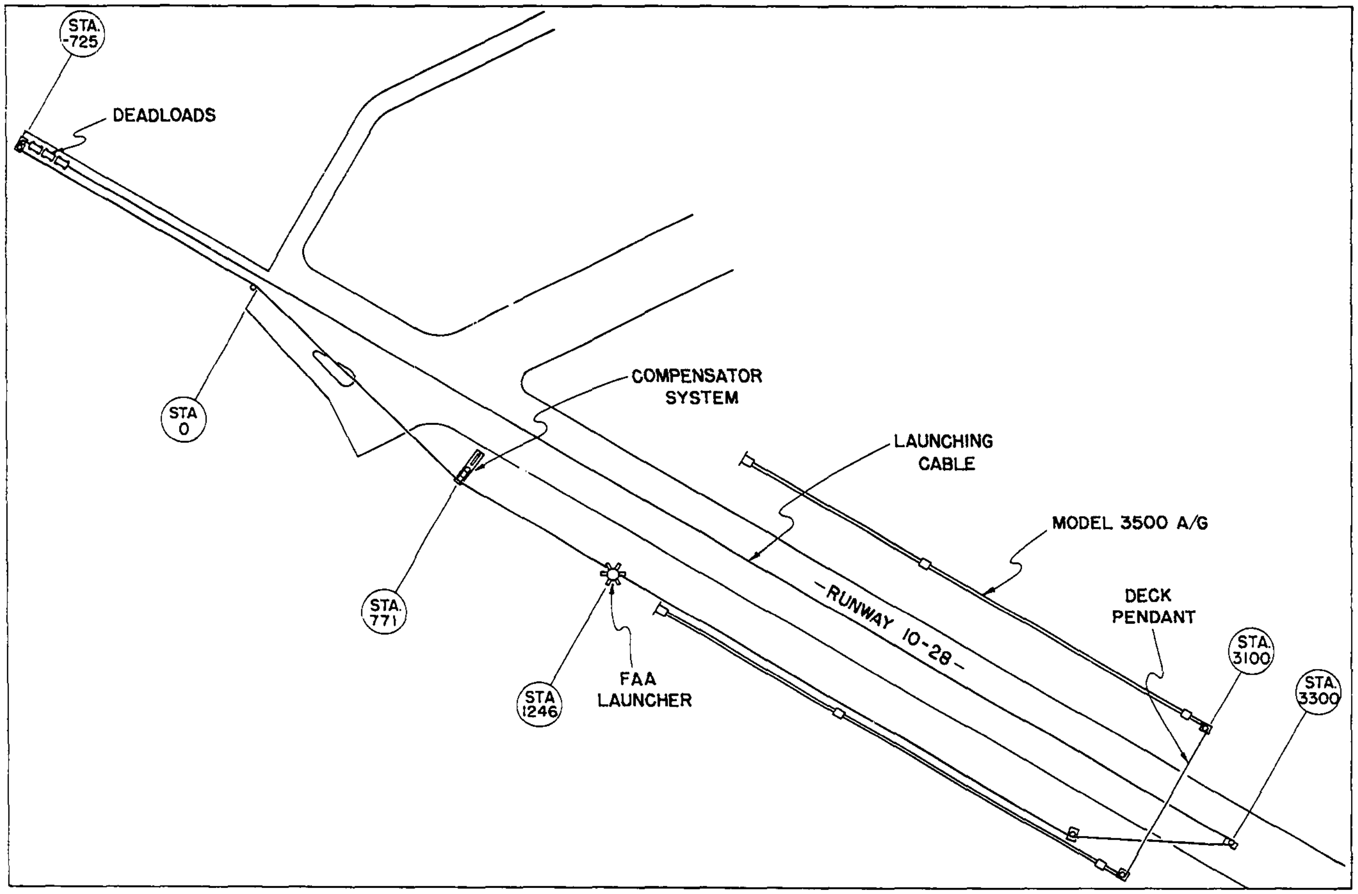


Figure 6 Layout of Model 3500 Arresting Gear and Launcher Used for Dead Load Testing at Sussex County Airport, Georgetown, Delaware

III. TEST EQUIPMENT

A. LAUNCHER.

The FAA Launcher was initially developed by All American Engineering, under contract to the Navy, as an expeditionary aircraft catapult for the Marine Corps. The original installation at the contractor's test site used an 800-foot accelerating stroke. This installation is described in All American Engineering Report N-135. The design, however, was ideally suited to a variable-length power stroke.

Developing the energy required to launch the dead loads in the Model 3500 development program was a problem of considerable magnitude. The energy available from the catapult had to be at least equal to the energy absorbing capacity of the arresting gear, or about 260 million foot pounds. Conversion of the Marine launcher to a long launcher stroke as shown in figure 6 was considered to be the most economical approach to the problem, particularly since the converted launcher would be available for other possible test and research uses.

The old installation was an 800-foot accelerator system. In conversion work, the power plant remained in position, and the cable was re-routed to extend from Station -725 to Station 3300 on the runway, giving approximately 4000 feet of launching stroke. An existing guide track, normally used to guide a jet car in other test programs, was extended 725 feet and used to guide the dead load and maintain the cable in a straight line. The total length of the endless loop of cable for the launcher is approximately 8200 feet.

Description of the FAA Launcher

The basic launcher consists of three major systems: 1, power plant; 2, control system; and 3, cable and cable guide system, including cable, capstan, cable compensator (pre-tension system), and sheave system.

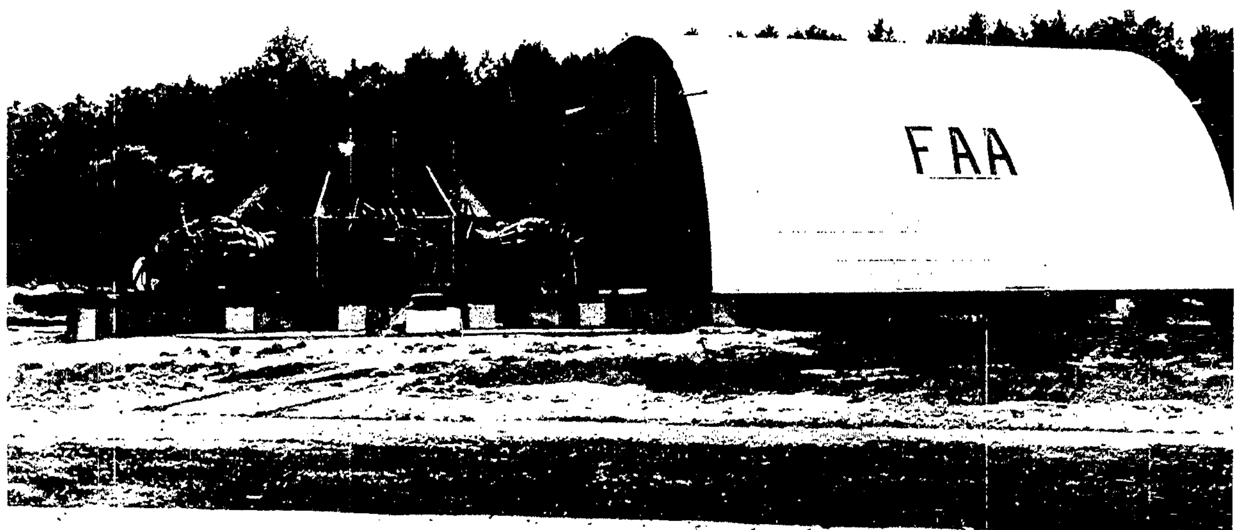


Figure 7 Launcher Turbine and Engines, Sussex County Airport, Georgetown, Del.

The catapult power plant system is basically a free gas turbine design. The main turbine wheel, 12 feet in diameter, rotates on a vertical shaft supported by two large bearings. The cable drive capstan is also mounted directly on this same shaft. Six Allison Model J33-A-16A jet engines are mounted radially about the turbine shaft to exhaust inward toward the shaft and up through the main turbine. Each engine is ducted to exhaust through 60 degrees of main turbine, and thus the six engines form a 360-degree admission turbine. The main turbine wheel is locked by a brake during the starting and checking of the jet engines. The brake is released at the beginning of a launch. Various energy outputs are obtained by changing the throttle settings of the jet engines and by varying the duration of power application during the launch stroke. The engines and turbine unit are shown in figure 7.

Starting and checking procedures for the jet engines are the same as for aircraft using these engines. The controls and instruments monitoring the percentage of rpm, tail pipe temperature, fuel boost pressure, and oil temperature are identical to those used on aircraft. The control console is pictured in figure 8.

The control system was designed with simplicity as a principal requirement. The jet engine throttles are push-pull control rods actuated manually by levers. The turbine wheel brake is actuated by a manual valve on the control console. A governor is provided in the jet engine fuel system to protect the engines from overspeeding.

In a normal launch sequence the turbine brake is set and the jet engines are started and brought up to idle speed. The launch is initiated by releasing the turbine wheel brake and simultaneously bringing the jet engines up to the desired power setting. Upon obtaining the desired dead load speed, as indicated on the console, the jet engine throttles are manually retarded to idle position. Cutting engine power actuates the cable clamp release, allowing the turbines and cable to slow down, and at the same time freeing the dead load for its run into the arresting gear. The catapult is normally allowed to coast in order to position the splice

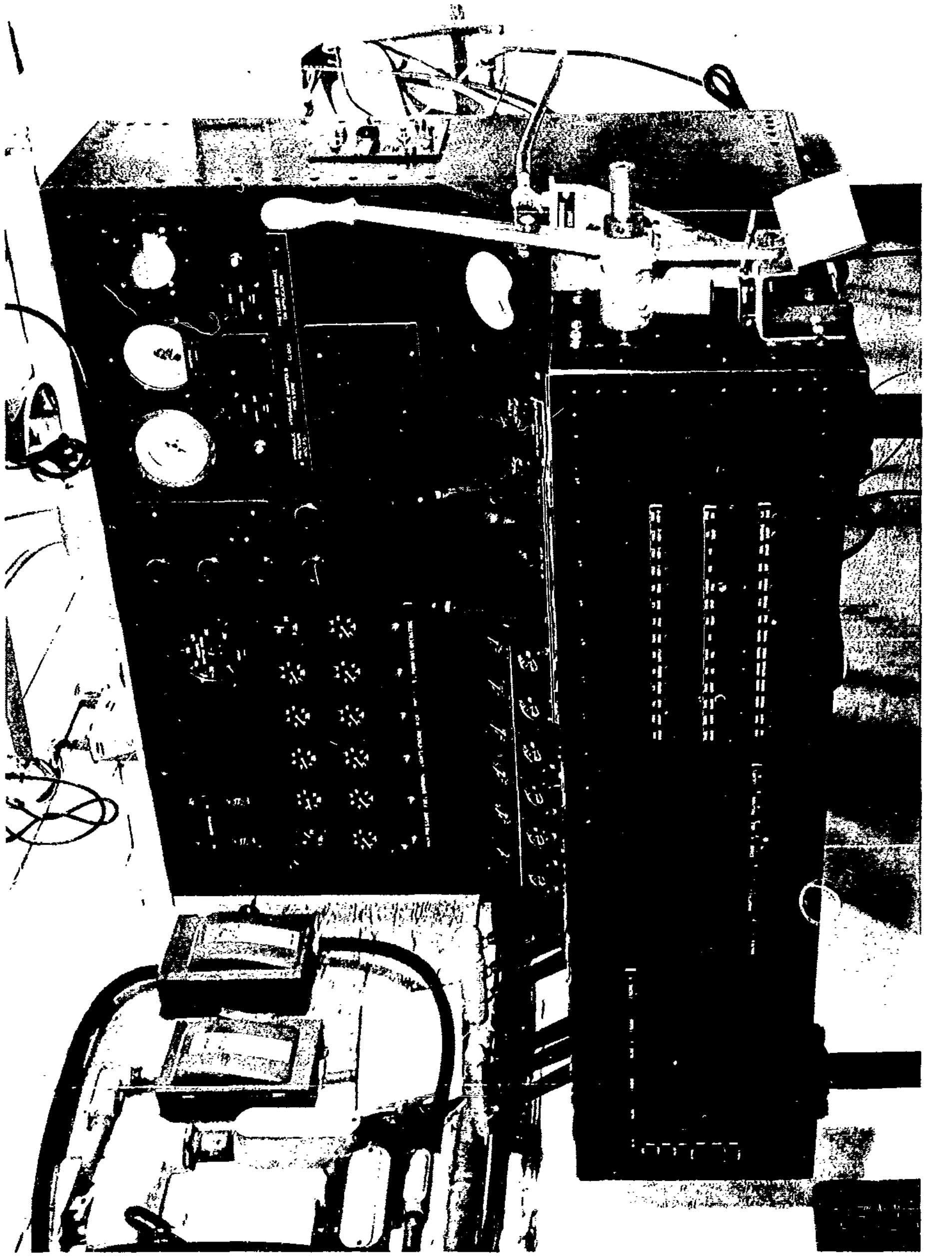


Figure 8 Launcher Control Console

in the endless cable on the slack side of the capstan for the next launch. As the splice comes into position, the turbine is braked to a stop.

The cable system is a long cable loop with a special long splice which maintains a constant cable diameter. Four loops of cable are maintained on the capstan, and cable tension is maintained by a hydraulic, pneumatic piston accumulator-sheave compensator.

The compensator system is shown in figure 9. During the power cycle the cable is stretched by the load applied. This pneumatic compensator (tensioner) also takes up the stretch in the cable. The cable used in the catapult is Right Lang Lay IWRC 6 × 37, 1-1/2 inches in diameter.

The cable is connected to the dead load by means of a cable clamp especially designed for this purpose. Wedge-shaped cable jaws are positioned so that a tension load on the cable and dead load forces the jaws into clamped position. As the load is removed, the jaws open up and release the cable. In addition, the jaws are positioned by a pneumatic accumulator and piston arranged so that the piston action opens the jaws at the end of the power stroke.

The much greater cable length of the modified launcher allowed greater total stretch and necessitated a method of removing slack in the cable produced by this stretch during a launch. The load exerted on the cable by the capstan drive essentially divides the cable into two parts during the launching operation. One part is known as the tight side and the other part is known as the slack side.

During this time the cable compensator was required to take up approximately 46 feet of extra cable.

The cable compensator consists of a fixed three-sheave assembly and a movable two-sheave assembly; the movable assembly is actuated by a hydraulic cylinder.

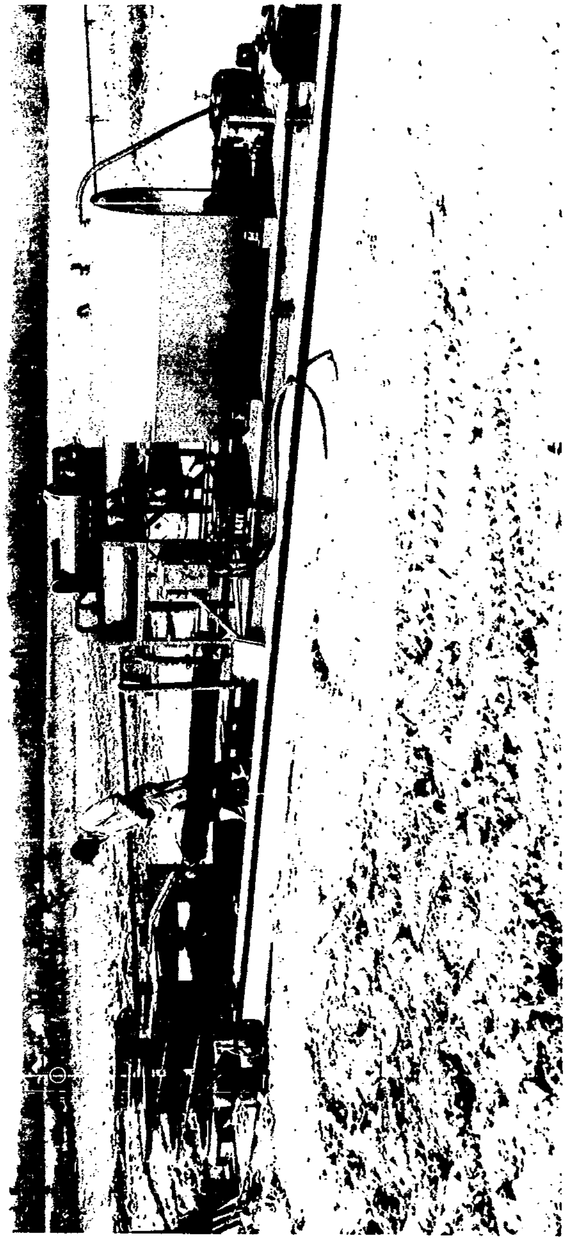


Figure 9 Launcher Cable Compensator

During a launch with a dead load attached to the shuttle, the catapult engines are started and, as the engine throttles are advanced, the capstan starts to turn. This causes the tight side cable to be tightened and stretched. This stretched cable is fed into the slack side cable system. During a launch the tight side is that part of the cable that runs from the shuttle to the capstan. The slack side is that part that runs from the back of the shuttle to the capstan. It is the slack part of the cable in which the cable compensator is situated. The function of the cable compensator is to maintain a nearly constant tension in this part of the cable during a launch.

On making a launch the capstan starts winding in the cable which pulls the shuttle. This cable tightens due to the inertia force of the load and stretches this part of the cable. This excess cable is fed into the slack side of the system and tends to lower tension on the slack side. Without the cable compensator, the cable tension in the slack side would become so low that it would allow the cable to slip on the capstan. This change in tension occurs at the initial part of the stroke and takes place in about six seconds of time. The compensator has four loops of rope, and with a stroke of twelve feet, up to 48 feet of excess cable can be taken up.

Since the cable pre-tension is 15,000 pounds, the cable compensator must apply a force of 60,000 pounds to hold the cable in position. The force of the cable compensator is developed through a hydraulic cylinder. This cylinder has a diameter of seven inches, and taking into account the piston rod area, we have an effective area that requires approximately 1900 psi of hydraulic pressure to develop this force of 60,000 pounds. The full stroke of the piston requires about 19 gallons of fluid. Since this stroke takes place in approximately six seconds, a quick calculation will show that this is over 190 gallons a minute of flow. Since this would require such a large pump and powerful engine to run it, accumulators are used in the system to supply the fluid for the cylinder stroke. The system consists of three 20-gallon piston and four 10-gallon bladder type accumulators. These are connected on the head end of the cylinder which powers the cable compensator. The system is pressurized with a hydraulic pump. The pump is of small capacity since it is only necessary to use this to pump up the system and hold it at this position and re-supply what oil might leak past the piston in the hydraulic cylinder.

To keep the tension constant there must be a means of providing a longer path for the cable. The lower cable tension is sensed through the cable compensator and the piston moves into the cylinder pulling the movable sheave with it. For each foot the piston moves, four feet of excess cable length is compensated for; hence, the name cable compensator. As the launch continues, the tensions are fairly constant to the termination of the launch. At this time the power is released, the load leaves the shuttle, and the tight side tension disappears. This requires that cable be fed back into the system again. This is taken back from the cable compensator, and as the piston moves forward it pushes the hydraulic fluid back into the hydraulic accumulators.

Before the hydraulic pressure is applied to the system, the accumulators should be pre-charged with dry nitrogen. These are pre-charged to a pressure of approximately 1600 psi.

The FAA launcher is the highest capacity catapult in existence today. It can provide approximately 260-million foot-pounds of energy. The energy utilized was limited to 200 million foot-pounds because of ambient temperature and stroke available prior to the arresting pendant.

Launcher Operation and Modification

The catapult was modified in early 1962 and testing began on 3 April. The use of a long cable and a reeved compensator resulted in dynamic problems during the launch. The cable slipped on the capstan at one time and slipped in the cable clamp another time. These problems were eliminated by modifications to the method of control, the number of cable loops on the capstan, the compensator system, and the cable clamp.

During a launch early in the program, cable slip on the capstan caused damage in the form of cable burn. A splice repair was made to the cable and the testing was resumed. The original pre-tension used was 10,000 pounds. To correct the problem of cable slippage, the number of cable turns on the capstan was increased from three complete turns to four complete turns, and the pre-tension load was increased from 10,000 pounds to 15,000 pounds. The remaining tests, including dead load weights up to 350,000 pounds, were completed without further difficulty with the cable pre-tension system.

There follows a resume of the launcher operations for the 55 successful launches made during the development of the Model 3500 arrester.

1. From 3 April 1962 through 3 October 1962, 55 successful launches were made utilizing the FAA Launcher. In addition to these 55 successful launches, three other attempts were made resulting in either a partial or complete abort.

2. After each launch the following inspections were performed:
   a. Turbine blades
   b. Upper diffuser turning vanes
   c. Tip shrouds
   d. Launch cable
   e. Compensator system
   f. Cable clamping jaws

3. At periodic intervals the following inspections were made:
   a. Lower bearings for foreign matter
   b. Sheaves
   c. Brake puck wear
   d. Capstan wear

4. At normal intervals the following maintenance was performed:
   a. Re-positioning of compensator hydraulic pad
   b. Installation of new cable jaws
   c. Repair of turbine blade cracks
   d. Increase in tip shroud clearance
   e. Tightening of inner ducting walls
   f. Disassembly and lubrication of sheave bearings

5. Changes incorporated during the test program were:

a. A new shut-off valve was incorporated in the compensator system

b. A new air cylinder was installed for cable clamp release

c. A more efficient means of relocating compensator hydraulic pad was incorporated.

d. Installation of new turbine blades

e. Installation of new launch cable

f. Removal of ridges on capstan

6. A crew of 8 technicians and mechanics was normally required during the testing period. This crew also retrieved the dead load.

See figure 22, Appendix A, for pertinent data.

B. DEAD LOADS

Dead loads to simulate aircraft for the track testing were required for use in this program. It was necessary that they be made to accommodate a weight range of 50,000 pounds to 350,000 pounds to cover the entire specification weight range of the arresting gear.

The dead loads used were three vehicles, each approximately 16 feet wide and 31-1/2 feet long, which could be used separately or in combination to obtain the proper test weight.

In order to minimize runway damage from repetitive vehicle bounce over a fixed line of motion, each dead load was suspended through four railroad spring-snubber units at each of six wheels. The wheels and tires were surplus 56-inch diameter B-52 units.

Each dead load was guided through the entire launch and arresting stroke by means of two flat vertical guides which were trapped within a recess or track within the runway. The guides were fixed with respect to the track surface vertically but permitted motion relative to the vehicle frame.

The vehicle frames were fabricated from longitudinal channel sections connected with box cross members and steel plate flooring.

Ballast was added to the vehicle in the form of steel reinforced concrete blocks, each weighing approximately 2200 pounds.

A special arresting hook and shoe were fabricated to engage the arresting gear. The dead load hook was mounted through a universal trunnion block to the last dead load in series. Accommodation was made to use the hook on the first or last dead load interchangeably. The overhead inverted hook was supported by means of cable suspension and frangible compression columns. Figure 10 shows the dead load hook in position prior to engagement.

In order to protect the launch cable from damage which might have occurred due to impact of the hook shank, an afterbody or extension was added aft of the rearmost vehicle and below the shank to limit downward travel of the rigid hook shank.

During the later tests, when the aircraft configured Sheaffer spring hooks were used, the dead load rigid hook was used as a back-up in case of failure. The spring hook was attached to a cantilever structure added forward of the rigid shank hook and at a lower hook point height.

During Run 38, when the hook point twisted loose from the Boeing 720 spring shank, the cable wrapped below the hook point of the rigid shank and was cut. A fairlead and skirt were added to the dead load shank for the ensuing tests, but no additional hook point failures were experienced.

The launcher shuttle or cable clamp was attached to the front portion of the first dead load and is covered in Section III A of this report.

Figure 10 Dead Load Arresting Hook Installation

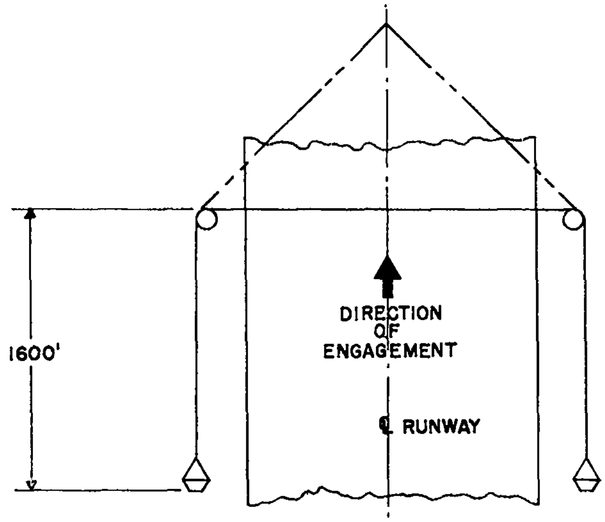


Figure 11a On-Center Test Configuration

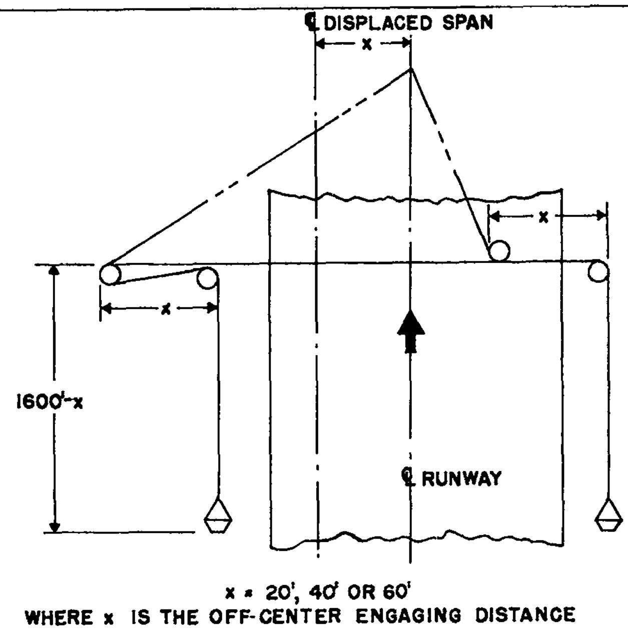


Figure 11b Off-Center Test Configuration

The dead loads were used in the following combinations during this program:

50,000 pounds - one dead load

200,000 pounds - three dead loads

300,000 pounds - three dead loads

350,000 pounds - three dead loads

C. OFF-CENTER SHEAVE ARRANGEMENT.

In order to perform off-center dead load tests on the Model 3500 arresting gear in accord with Amendment 4 of this contract, a special reeving of the arresting gear was made.

The dead load track and arresting engine mounting could not conveniently be varied. Instead, extra sheaves were added adjacent to the existing deck sheave foundation which permitted an infinite off-center adjustment from about ten through 60 feet. A schematic layout of this sheave arrangement may be seen in figure 11b. This arrangement permitted utilization of the standard arresting cable configurations with variation only in the battery position of the pistons.

The only difficulty experienced was during Run 34 when a sheave guard failed, permitting the cable to jump off the sheave but resulting in a satisfactory arrestment. The sheave guard was strengthened with no further difficulty resulting.

D. INSTRUMENTATION - MODEL 3500 ARRESTING GEAR PROGRAM

Dead Load Tests.

On the Model 3500 arresting gear dead load test program, the parameters measured on the various components are specifically listed in Test Plan 1476-1, Revision C. The techniques used to obtain these measurements are outlined below:

(a) Arresting Gear. All of the measurements made on the arresting gear were recorded on a Century Model 408 oscillograph which has a tuning fork stabilized oscillator to supply an accurate time base for the data. Most of the transducers were a strain gage sensor type with the signal conditioned with a B & F Model 12-200 bridge balance unit. Power for the transducers was supplied from a B & F Model 6-12-24 regulated power supply. The entire gear instrumentation complement was housed in an instrumentation trailer located at the gear site near the port tube.

Cable tensions were sensed with three-sheave tensiometers completely designed and constructed by All American. These tensiometers were statically calibrated at Swarthmore College in Swarthmore, Pennsylvania, on the college's 600,000-pound capacity pull test machine (see figure 12). The pressure transducers were Taber Model 176 Teledynes and were calibrated with an Amthor dead weight pressure tester.

The only measurements on the arresting gear which were not made with a strain gage type sensor were the engaging velocity of the dead load and the cable velocities. These data were collected by installing magnets on the dead load and the cable sheaves and letting the magnets pass over coils located known distances apart. The EMF generated in the coils as the magnets passed over them was recorded on the Century Model 408 oscillograph against the time base of the instrument; hence, velocities could be computed.

(b) Dead Load. The dead load carried two Century Model 409 oscillographs with batteries for transducer excitation and instrument operation. The signals were conditioned with two B & F Model 6-100 bridge balance units, and again the transducers were strain gage type sensors.

Two separate sets of instruments were used so that acceleration data, which occurred over a relatively long period of time, could be recorded separately from the deceleration data, which occurred over a relatively short period of time. The acceleration data consisted of the towing force on the dead load, an accelerometer signal, and cable slippage. The towing load was sensed with a strain gaged link mounted in series with the cable grab and the dead load. This link was calibrated on All American's static pull test machine. The accelero-

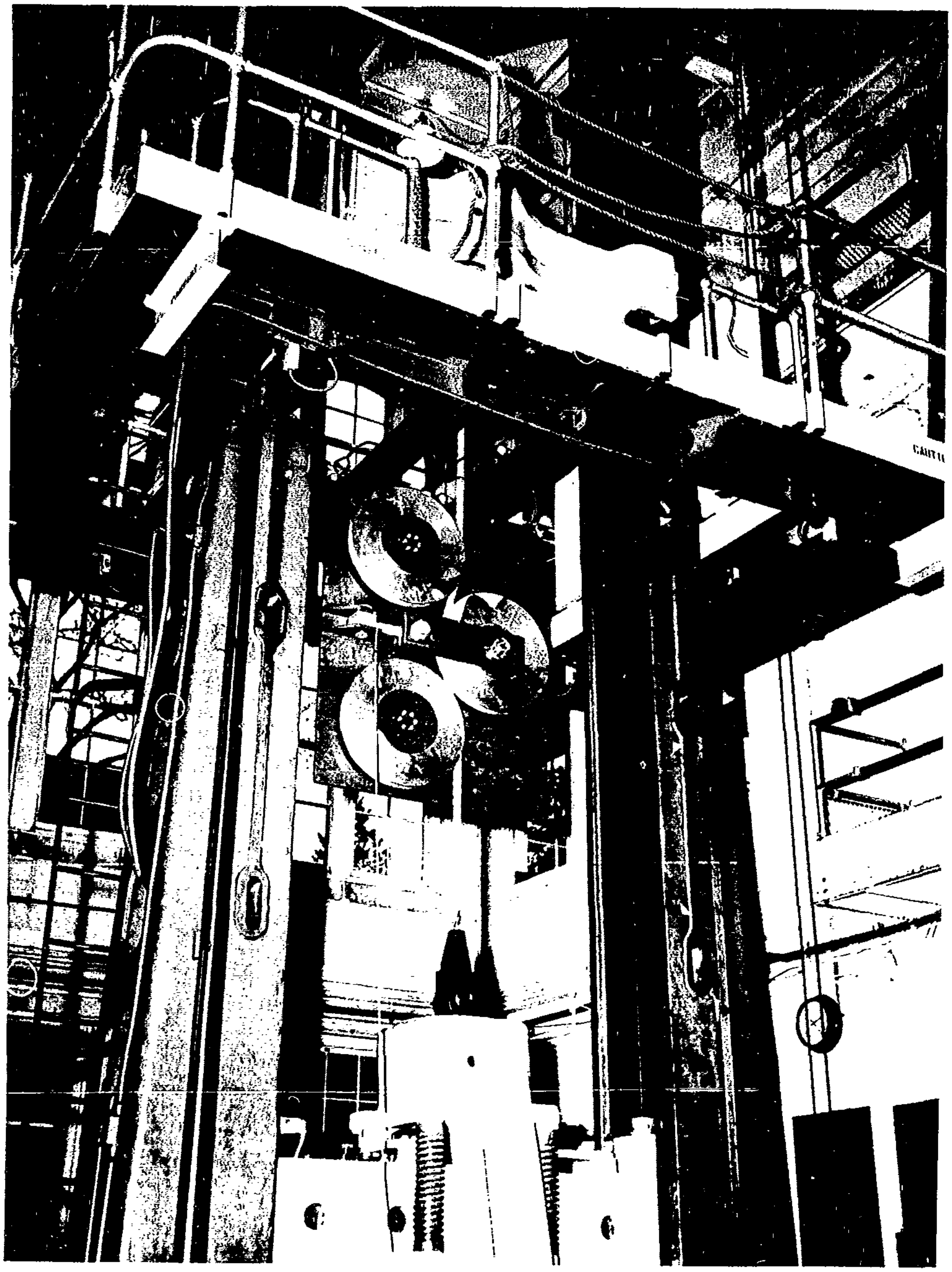


Figure 12 Three-Sheave Tensiometer Being Calibrated

meter used was a B & F Model LF-3-20. Cable slippage was measured with a rotary potentiometer which was fixed to the dead load and had a friction drive wheel pressed against the cable; as the cable moved relative to the dead load, a change in resistance on the potentiometer gave a signal proportional to the motion.

The deceleration measurements consisted of hook load and deceleration. The hook load was always measured with the same technique (strain gages on the hook shank) with the assembly calibrated at Swarthmore College. This technique was used for all hook load sensors, including those used on the aircraft tests. The deceleration was measured with a B & F Model LF-3-20 accelerometer.

(c) Federal Aviation Agency Launcher. The launcher data were recorded on the same types of equipment which were used on the arresting gear. The cable tight side tension, when recorded, was sensed with a tensiometer exactly like the model used on the arresting gear. The slack side tension was sensed with a strain gaged link in series with the movable sheaves on the cable compensator. This link was exactly like the one used to sense dead load towing force. Velocities of the cable, the capstan, etc., were recorded with the same technique as described for the dead load velocity, i.e., coil and magnet and the oscillograph timer.

Aircraft Test.

On the aircraft tests with the Model 3500 arresting gear, the parameters that were measured are specifically listed in Test Plan 1476-4, Revision A (see Appendix B). The various techniques to obtain these measurements are outlined below:

(a) Arresting Gear. The arresting gear measurements were made the same on the aircraft tests as they were on the dead load tests, except that fewer channels of pressure were measured.

(b) C-131. The only measurements made on the C-131 were deceleration g's, hook load, and hook position. The hook load was measured by strain gaging the C-131 hook shank and calibrating the entire assembly at Swarthmore

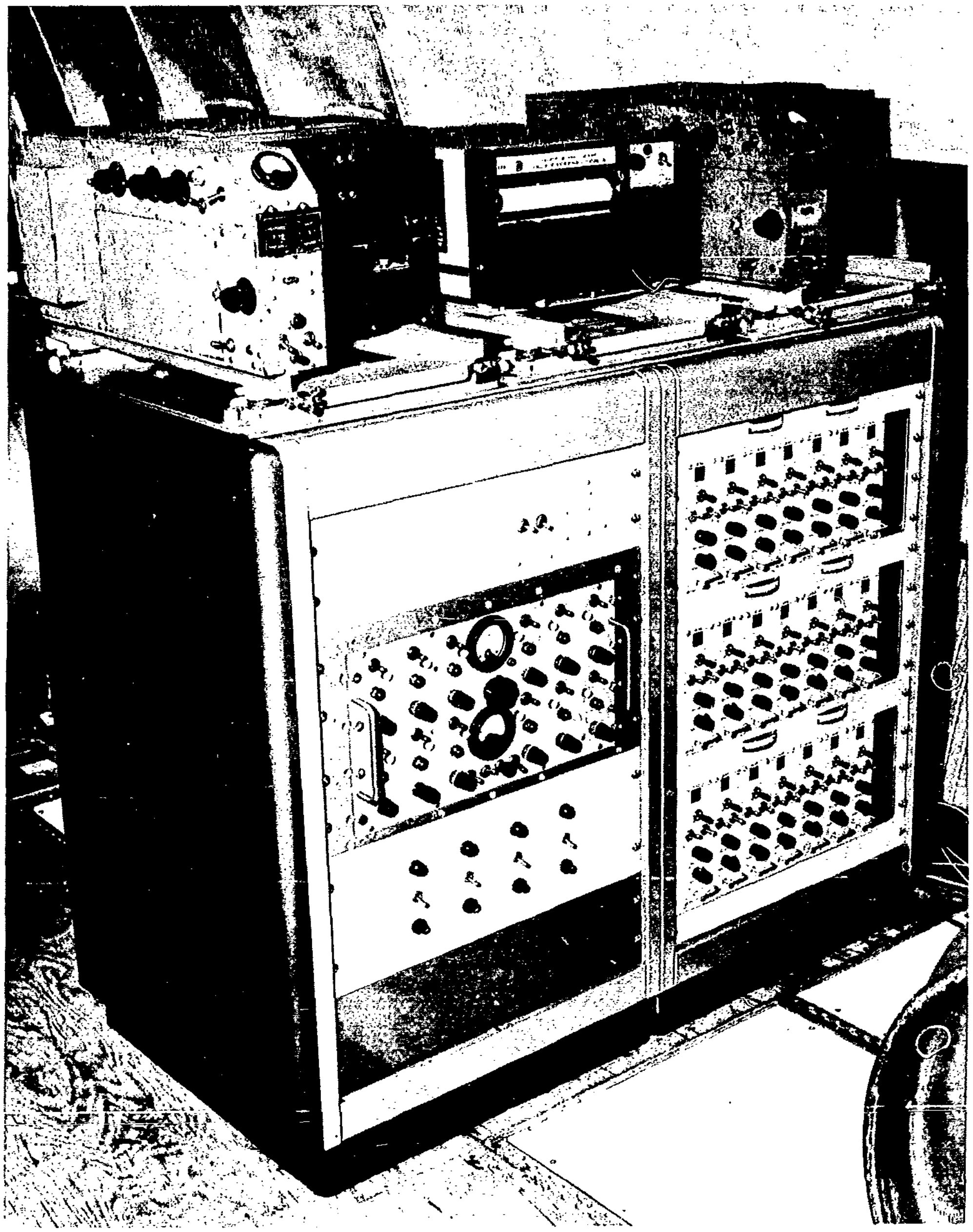


Figure 13 Instrumentation Console in Boeing 720, N113

College. The deceleration g's were measured with the same accelerometer that was used on the dead load at Georgetown. The measurements were recorded on a Century Model 409 oscillograph with the signals conditioned with a B & F Model 6-100 bridge balance unit. After the first few runs utilizing aircraft power, a separate battery was installed in the aircraft to operate the instrumentation.

(c) Boeing 720. On the Boeing 720 aircraft several channels of strain data were recorded (see Appendix C, Part II) as well as the hook load and deceleration.

All of the transducers were of the strain gage type, except the hook position transducer which was a rotary potentiometer. The strain gages were foil type gages purchased from the Budd Metal Company's Instrument Division. All of the transducers and strain gages were excited with Sorensen Model QM regulated power supplier, with the power for the QM supplier taken from the aircraft's 400 cps electrical system.

The transducer signals were conditioned with All American Engineering Company's Model 1-03-10 bridge balance units, with the output signals recorded on three oscillographs. The oscillographs were two Century Model 408's and one CEC Model 5-124 direct writing model. All of the signal conditioning and recording equipment was mounted to two standard relay racks 32 inches tall, and these were secured to the aircraft floor in place of one of the water ballast tanks. Figure 13 shows the instrumentation console in the Boeing 720.

Figure 14 Dead Loads Making Engagement With Overhead Pendant

IV. TEST PROCEDURES

A. DEAD LOAD TESTS.

The procedure for launching the dead load into the arresting gear was as follows.

The dead load was positioned at battery, the launcher drive cable positioned as described in Section III, and the dead load cable clamp secured to the launcher cable. Area clearance and instrumentation readiness were verified by the test conductor and the launcher operator given a go-ahead for the shot. The launcher brake was then released and the throttles advanced to the prescribed position, depending on dead load weight and specified engaging speed desired.

After the launch cable and dead load accelerated to the desired speed, the throttles were retarded and the cable clamp automatically disengaged. The dead load then coasted into the arresting gear which was in battery with cross deck pendant supported and tensioned about 60 inches above the runway. The dead load ran under the cross deck pendant to engage the pendant with an inverted arresting hook; the arresting gear then stopped the dead load. Figure 14 shows the dead load passing under the pendant and just engaging.

The runout and other pertinent information was noted and recorded and the dead load returned to battery for the next shot. The arresting gear was retrieved, retrieve line faked or replaced by another line already faked, the water level checked, and the instrumentation set up for another arrestment.

The test plan for the first 20 engagements specified a schedule of events in order of increasing kinetic energy to allow monitoring launcher and arresting gear performance. The dead loads were weighted to 50,000, 200,000, and 300,000 pounds, and tested at speeds of 60-100 knots for the 50,000-pound series, not over 130 knots for the 200,000-pound series, and not over 120 knots for the 300,000-

pound series. Test events were not delayed or repeated for instrumentation failures, provided the items were not contractually required (see Test Plans 1476-1 and -2, page B-2 and B-12. Three events in excess of the planned 20 were made to pick up items which were required.

Amendment 3 to the contract provided for an additional seven dead load arrestments at 350,000 pounds.

By amendment 4 to the contract, 20 additional engagements were provided at varying weights and varying distances off-center, including 20, 40, and 60 feet. Twenty-five arrestments were made in this series, the additional arrests being made to pick up required but missed instrumentation points and to provide one arrest at a speed of 135 knots at 200,000 pounds.

B. AIRCRAFT TESTS.

The general procedure for conduct of the aircraft arresting gear engagement tests was as follows. A brief meeting just prior to an operation established the weight, speed, and type of engagement (on-center, off-center) for the forthcoming arrestment. A time for the test was established, and the participants took their positions. The contractor was responsible for readiness of the arresting gear and its instrumentation plus aircraft instrumentation. About thirty minutes prior to test, the fire crew positioned its equipment on the field and the aircraft crew manned the plane.

The contractor representative checked the arresting gear and instrumentation and reported to the NAFEC test conductor when ready. The NAFEC test conductor reported to the NAFEC project manager who then checked the runway, received a clearance from the control tower for the run, and cleared the plane for its run into the arresting gear.

Since fuel consumption is a considerable item in operation of the jet transport, the Boeing 720 was not cleared to start engines at the ramp until all other units were in place and ready.

All runs into the arresting gear were made on runway 13. As the aircraft crossed a runway intersection approximately 500 feet before reaching the pendant, the co-pilot gave a signal to the instrumentation engineer to start oscillographs and then lowered the arresting hook. As the aircraft reached the desired speed, the pilot cut his throttles and, as the plane came to a stop, he applied brakes to hold his position. On some runs no brakes were used to verify full stop without brake application. Upon receipt of signal from the plane director, the pilot applied reverse thrust and backed down enough to allow disconnecting the pendant from the arresting hook.

In the case of the Convair 131, the pilot raised the hook by controls in the cabin. The Boeing 720 spring hook installation required manual hook restoring and replacement of retainer clip and cartridge cutters. The spring hook is released by the pilot closing an electrical circuit which fires explosive cutters, cutting the hook clip supporting bolts.

Figure 15 shows the test location at NAFEC.

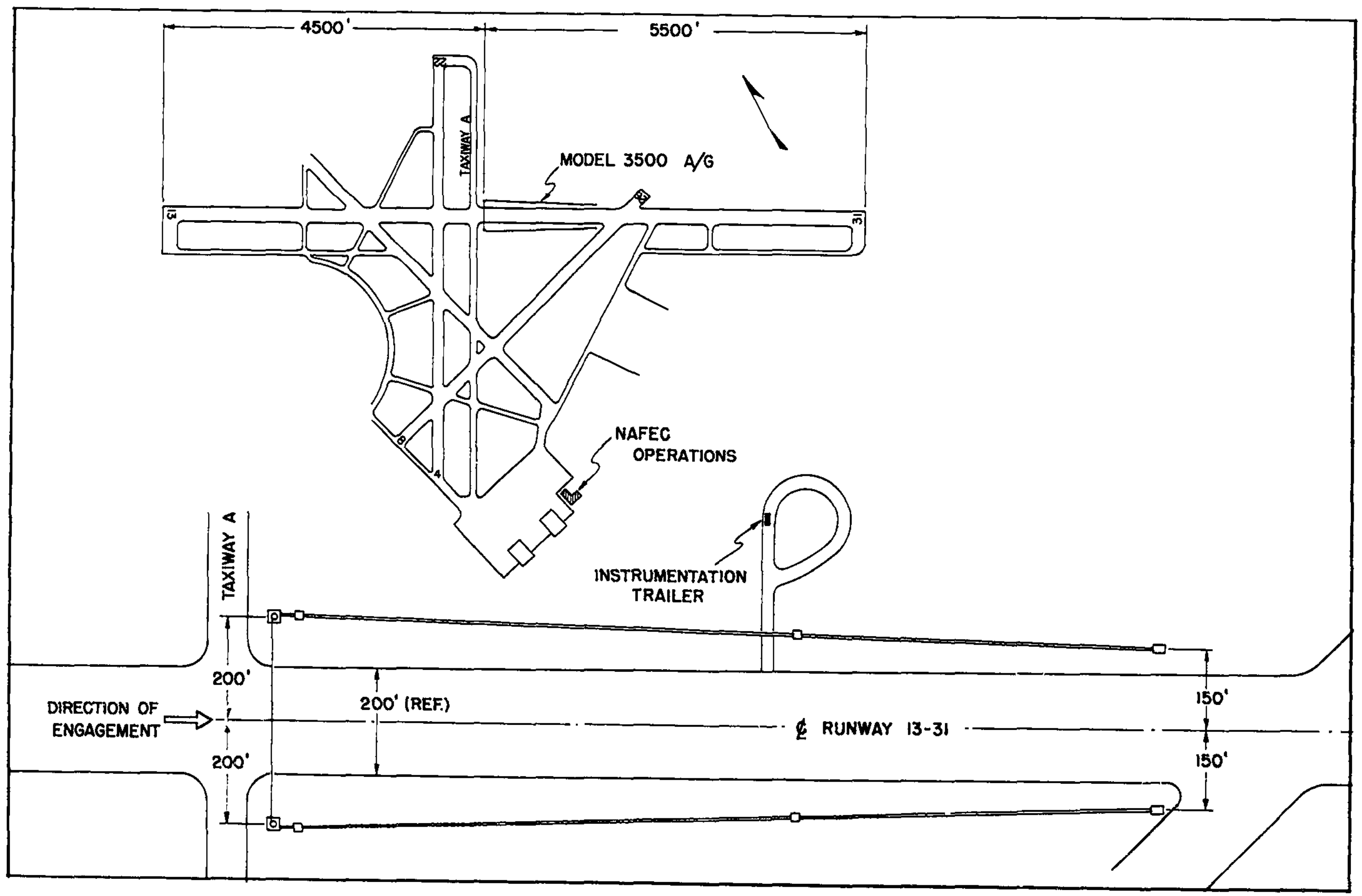


Figure 15 Layout of Model 3500 Arresting Gear Site for Aircraft Testing at NAFEC, Atlantic City, N. J.

V. DISCUSSION OF RESULTS

A. DESIGN AND DEAD LOAD TESTING

Spring Hook Shank Redevelopment for Boeing 720 Aircraft.

The original Sheaffer spring hook (AAE Part No. 7251) developed under Contract FAA/BRD-304, Amendment 1 (reference All American Engineering Company Report M-657A) was fabricated out of 17-4 PH stainless steel. This original hook was designed under the concept of tail hook shank replacement after each arrestment, since it was intended for minimum weight and emergency use only. However, the 17-4 PH material has a relatively low transverse ductility, and one shank had failed prematurely during a previous static test (see AAE Report M-657A).

In order to meet a 100-cycle load life to limit design load (225,000 pounds), a re-design was appropriate. A new hook shank was designed utilizing heat treated SAE 4340 steel and a larger attaching boss to transfer load from the hook point.

On 24 July 1962 a prototype shank was tested on the 600,000-pound Baldwin-Lima-Hamilton test machine at Swarthmore College, Pennsylvania. The shank was pulled to 225,000 pounds for 110 cycles without any evident yielding or fracture and then pulled to destruction at 358,000 pounds. Figure 16 shows the shank in place on the test machine, and figure 17 shows the fractured shank. The fractures were transverse to the shank and occurred in two places simultaneously. Inspection disclosed a conventional conical tensile fracture.

Upon satisfactory results of the prototype testing at Swarthmore, four additional shanks were fabricated, one for dead load testing and three for use during the aircraft tests.

The dead load tests in which engagements were made with the new Boeing 720

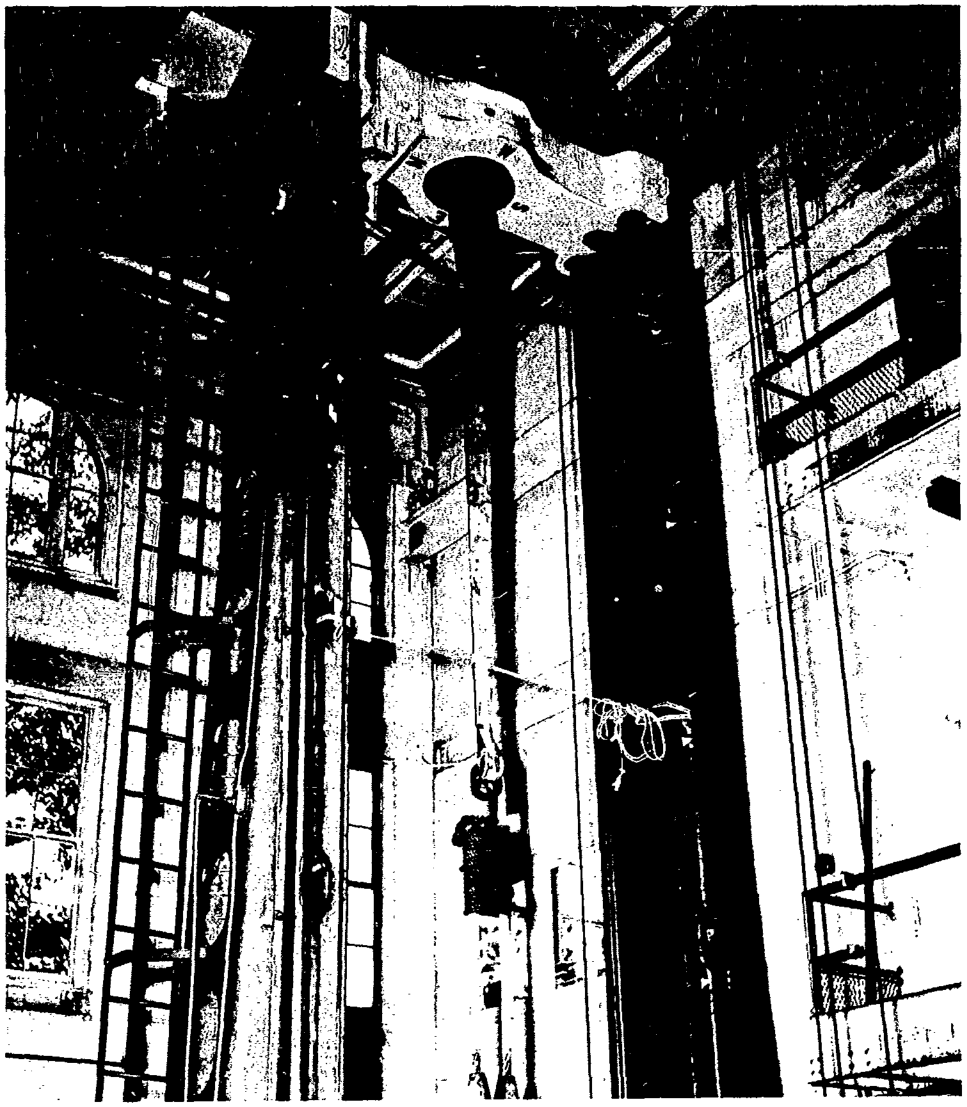


Figure 16 Sheaffer Spring Hook for Boeing 720 Being Proof Tested in 300-ton Pull Test Machine

Sheaffer spring hook were Runs 36 through 47. No difficulties were experienced with the hook shank during the dead load testing.

Development of Hook Point for Boeing 720 and Boeing 707 Aircraft.
The original hook points used during the FAA engagement feasibility tests at NATF, Lakehurst, were made from 2024 aluminum alloy. Some difficulty was experienced during these previous tests with failure of the web at the base of the attaching bolt recess (see All American Engineering Company Report M-657A). The impact of the hook shoe on the runway caused the shoe to detach from the shank. The design of the aluminum alloy hook point was revised to increase the web thickness and eliminate stress concentration in the corners. However, although the aluminum shoe proved adequate in all other respects during the Lakehurst tests, a higher strength, hard coated cable groove hook point was known to be necessary for off-center arrestments. Hard coating in the hook point groove reduces the torsional shoe loads on the shank and prevents machining of the cable groove by the deck pendant wires during cable wiping. A soft, ductile material in the hook point throat causes the deck pendant wires to seize, thus causing differential cable tensions to be resisted by torque into the hook point and shank. Hard coating of the cable groove permits the wire rope to slide rather than seize and thereby equalizes tensions on both sides. The hard coating also lessens wire damage of the deck pendant. The maximum pendant transfer through the hook throat during dead load testing was 34 feet, but no wires were broken by seizing during any runs.

During dead load Test 38 (at an engaging velocity of 119.2 knots and 40 feet off-center) an interim SAE 4130 steel hook point came loose from the Boeing 720 hook shank by failing to resist the torque. There was a material bearing failure at two corners of the hook point slot, causing failure of the 1/2-inch diameter attaching bolt due to induced tension. This failure caused the deck pendant to release from the spring hook and break upon wrapping around the lower sharp edges of a second back-up dead load hook point. This resulted in a runaway dead load which was retrieved with very minor damage after travelling about three-quarters of a mile beyond the test track area.

Figure 17 Double Fracture of Boeing 720 Spring Shank During Destructive Testing

An identical interim hook point was modified to increase the bearing contact area of the point on the hook shank and increase the retaining bolt size from 1/2- to 3/4-inch diameter.

The Boeing 720, 707 hook point was designed to utilize 17-4 PH stainless steel shoe material with a Colmonoy No. 6 hard coating in the cable groove. The new hook point is shown in figure 18. This 17-4 PH stainless steel hook point was tested with satisfactory results on the dead load during Runs 53, 54, and 55.

Spring Hook Shank Development for the Boeing 707 Aircraft.

A hook shank was designed and made from Maraging Steel 18 NiCoMo/300 (having an ultimate strength of 300,000 pounds per square inch) for application to the Boeing 707 aircraft. This shank also was designed to withstand 100 stress cycles to limit load (350,000 pounds).

Proof loading was conducted on 28 and 29 August 1962 at Swarthmore College. The prototype shank withstood 100 cycles to 350,000 pounds and was then pulled to destruction at 489,000 pounds. The test setup was similar to that shown for the Boeing 720 shank (figure 15). Fracture of the shank occurred as a single fracture in approximately the same area as the Boeing 720 shank.

The maraging shank was tested without incident on the dead loads during Runs 53, 54, and 55.

C-131B Hook Point Re-design.

The original hook point on the C-131B was an unmodified AD hook point (NAEL Part No. 604324-1). This hook point possessed insufficient cable groove diameter, cable bending diameter, and clearance to the hook shank for the 1-1/2-inch-diameter Model 3500 arresting gear cable.

Two 17-4 PH hook point forging blanks for the F4D were modified to accommodate the C-131B shank (AAE Part No. 12SK353). These were also hard coated with Colmonoy No. 6 in the cable groove and heat treated to an ultimate tensile strength of 280,000 psi.

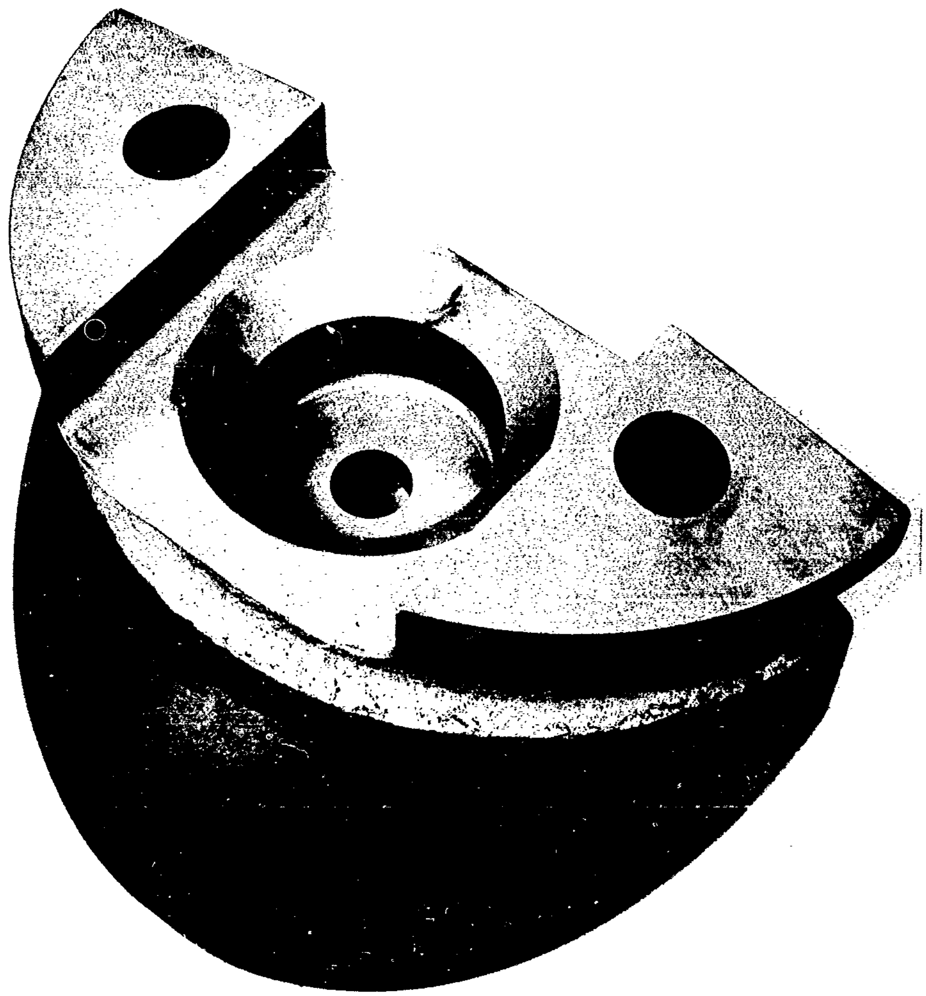


Figure 18 Hook Point for Boeing 720, 707

The hook point was proof-loaded during strain gage calibration of the shank assembly at Swarthmore College prior to the aircraft testing at NAFEC. No dead load tests were run with the C-131B hook point.

Arresting Gear Test Modifications.

Only minor modifications to the Model 3500 arresting gear were found necessary and desirable during the dead load program.

During dead load Run 21 the eye fittings at the aft portion of the pistons, for attachment of the retrieve leaders, failed on the port and starboard side due to torsional loads. In an effort to alleviate this difficulty, an increased strength eye fitting was used during dead load Run 22. During Run 22 both retrieve leaders failed due to excessive torque which tightened the rope helix and continued to over-twist the leaders to failure. A ball-bearing swivel was incorporated at the aft end of the piston during Run 23. No further over-twisting of the retrieve leaders was experienced, and therefore the ball bearing swivel was incorporated into the Model 3500 design.

Experience with previous water-squeezer arresting gears had indicated the desirability of a unique swivel design for use between the deck pendant and purchase cables. With a long run-out arresting gear utilizing conventional wire rope construction, the helical strand shape results in an untwisting during tensioning and a rapid re-wind during relaxation. This phenomenon necessitates a swivel intermediate to the airplane and deck sheave to permit the re-winding of the wire rope about its longitudinal rope axis. Failure to provide a swivel, or a malfunction in same, causes the rope to coil about itself, resulting in a damaged purchase cable and/or deck pendant due to kinking.

All previous water-squeezer arresting gear designs had a modified commercial swivel. These swivels were well able to withstand the longitudinal tensile loads. However, the severe shock loading combined with lateral loading and high rotational velocities (above 3000 rpm) imposed by the kink wave, caused by

Figure 18a Model 3500 Swivel and Link Assembly

transverse engagement, caused accelerated bearing roughness (dynamic brinelling) and in many cases complete bearing race failure. Larger bearing capacities were not the answer due to the fact that higher capacity bearings increased the swivel mass, which in itself increases the lateral loading.

Prior to the award of Contract ARDS-437, the author invented a swivel to fulfill the requirements of unrestricted swiveling during tension relaxation and at the same time reduce the required bearing capacity without any performance penalty. This design permitted a limited bearing loading and free rotation only under low tensions. During high longitudinal tensions, rotation through the swivel is reduced through internal friction, and all stresses above a nominal design limit by-pass the ball bearing. In addition the adjacent wire rope swaged fitting on the pendant side of the swivel was attached directly to the swivel rather than through the more conventional swivel clevis-to-eye-ended deck pendant fitting. This reduced the swivel design problem by reducing the moment arm of the transverse loads exerted on the swivel.

This swivel design (see Figure 18a) was applied to the Model 3500 arresting gear. Initial dead load testing indicated the need for two minor improvements.

The first improvement was relocation of the gap between the two rotating parts of the swivel. This gap was originally in a plane normal to the swiveling axis. At times it became partially filled with soil and debris which restricted free swiveling under low torque. The swivel was re-designed to place the gap on the end, and no further difficulty was experienced.

Also, some slight bending in the main swivel shaft was noted after repetitive arrests. This was caused by kink wave impacts. A shorter unique swage design, worked out jointly between All American Engineering Company and Bethlehem Steel Corporation, combined with a higher tensile swivel shaft, eliminated this difficulty.

These modifications to the original Model 3500 arresting gear design were the only significant ones made, except for the pre-tensioning system which was planned to be changed on transition from dead load to aircraft testing. Overhead engagement with dead loads does not duplicate the problems inherent in pre-tensioning for aircraft service. The pre-tension system used in the aircraft tests is described later in the text.

Arresting Gear Dead Load Test Data.

During the dead load test phase a continuous monitoring of pertinent arresting gear performance parameters (see Test Plan 1476-1, Appendix B) was performed in order to evaluate the performance of the equipment against the contract specifications, to determine suitability and compatability with aircraft and passenger restrictions and comparison with theoretical and empirical expectations. Continuous and thorough data evaluation was imperative in order to proceed to more severe test conditions without great risk of subsequent failure and resultant consumption of money and time. The magnitude of energies was far beyond the state of the art, and damage resulting from failures could have been of catastrophic proportions.

Following is a discussion of the important findings for each of the most critical performance parameters.

(a) Cable Tensions. Cable tensions are discussed in terms of the physical phenomena generating them. These are of two types: dynamic and hydraulic.

The dynamic tensions are a result of the lateral and longitudinal waves generated in the cable by hook impact with the deck pendant. Their effect is of relatively short duration but of great significance, since they can limit the engaging velocity potential of the arresting system. Dynamic cable tensions are influenced little by the energy absorber except as it dictates geometry of the system and mass per unit length of the cable.

Hydraulic cable tensions in a water-squeezer result from the frictional cable drag, caused by the wetted cable being transferred through the fluid, and the pressure drag exerted on the piston at the end of the purchase cable. The piston drag is of greater magnitude than cable drag. The Model 3500 arresting gear is of the diving piston type wherein the initial piston motion is through a dry tube. This initial dry tube is provided in order to not superimpose high magnitude piston drag tensions on dynamic tensions.

Further, the Model 3500 arresting gear has such a wide weight range of vehicles to accommodate (50,000 to 350,000 pounds) with low "g" loads on all, that the dry tube was extended so that the minimum weight vehicles would be retarded primarily by cable drag tensions rather than piston drag. This scheduling of tension application permits a more versatile vehicle weight range accommodation than is possible by most other types of arresting gears without some means of control.

The Model 3500 arresting gear was designed to operate within 66 percent of minimum guaranteed cable breaking strength. This figure has been established as a reliable one through past experience with lower capacity arresting gears using wire rope as tensile members. It should be noted that tensions higher than 66 percent of minimum cable breaking strength should not be applied repetitively since this would be beyond the construction yield of the cable.

Cable dynamics are composed of three significant waves or peaks. The first is termed "initial impact tension" and is a longitudinal tension wave generated by aircraft hook impact on the arresting cable. It propagates from the impact point to both sides of the hook at the speed of sound (approximately 11,000 feet per second) and is relieved in magnitude by piston motion. The second dynamic wave is a triangular kink wave which also propagates from the arresting hook toward both deck sheaves but at a much reduced velocity (about 590 feet per second at 130 knots engaging velocity) from the longitudinal wave. The kink wave velocity and wave angle are proportional to engaging velocity. This wave results in a tension peak upon impact with the deck sheaves. After impact of the first kink wave from the deck sheave it reflects back to the aircraft hook. Upon reaching the hook, a third rise in tension results, termed "second hook impact". These three dynamic tension buildups are the significant ones. The highest in magnitude is generally that caused by impact of the kink wave on the deck sheave and is generally a fixed proportion (1.5 times) of the theoretical initial impact tension. After exceeding the condition whereby the kink wave reaches the deck sheave prior to a pay-in of cable from initial piston motion, there is generally a rapid increase in the proportion of sheave impact tension to initial impact tension. Off-centerline engagements have the effect of moving the point of propagation of the slower moving kink wave closer to the deck sheave and therefore generally result in the most severe engaging condition, thus limiting performance.

In design, the relationship of deck span to total cable length is set to provide performance within the 66 percent of cable breaking strength at the maximum design off-center engaging distance and velocity.

There are other means of decreasing the sheave impact tension buildup such as with elastic elements in series in the cable system or yielding deck sheaves. However, the least complexity and the most easily defined performance calculations are based upon a properly designed geometrical layout.

The Model 3500 arresting gear was designed for 130 knots maximum engaging velocity at 20 foot off-center engagements. However, testing revealed a ratio of sheave impact tension to theoretical impact tension (hereinafter called Z') of 1.5 even when the kink wave reached the end sheave at or prior to the time of cable transfer around the deck sheave from initial cable motion. That is, there appeared to be no significant superposition of sheave impact tension as other designs had exhibited. This is attributed to one of three possible reasons, or possibly a combination. The first is that the larger than normal cable diameter and stiffness caused kink wave dampening by reduction in the effective kink wave angle. The second is that the large span caused a dampening of severity of sheave impact by a greater reduction in wave angle. The third is that perhaps the greater total elasticity or construction stress in the larger span created sufficient incremental stretch buildup to reduce the severity of sheave impact tension.

The data (see figures 23, 24 and 30 through 33 in Appendix A) show extrapolation through 130 knots to exert less than 66 percent and, therefore, acceptable tensions throughout the design range.

The hydraulic cable tensions expected are determined by means of computer calculations which make use of empirically verified frictional and pressure drag coefficients. Review of figures 34 through 37 illustrates that, although computed hydraulic cable tensions were comparable with those experienced with dead loads of lighter weights, the higher weights showed a significant reduction in tensions experienced over those computed. These were a welcome result, since the effect was from a lower peak-to-mean tension rather than a failure in energy absorbing capacity caused by reduced drag coefficient.

(b) Hook Load. The aircraft longitudinal hook loads are generated by the cable tensions discussed in the preceding section. However, the geometrical effect of arresting cable payout yields a characteristic difference in the relationship of succeeding hook load peaks from that of cable tensions. That is, peak dynamic hook load occurs at the impact of the reflected kink wave at the aircraft hook, or second hook impact, whereas the dynamic cable tension peak occurred at impact of the kink wave at the deck sheave.

On most arresting gears peak dynamic hook load is from 2.5 to 3 times theoretical initial hook tension (Z factor). Figures 38 through 41 reveal that the dynamic hook load experienced during the dead load series is apparently greater than three. However, figure 39 shows a gross departure between data accumulated with the spring hook and that of the rigid shank. The reason for this is not that a different load was experienced, but rather, more than true longitudinal hook tension was measured with the rigid shank. Because of the large angle of rotation in dropping after engagement and subsequent lateral impact on the dead load after body, the strain gages on the shank were reading the effects of lateral shock in addition to longitudinal tension.

Theoretically, dynamic tensions are not a function of vehicle weight except that, on impacts after initial impact, the instantaneous vehicle speed determines the magnitude of each buildup. Lighter weight vehicles decelerate more rapidly before sheave impact and therefore result in lower peak dynamic hook load.

On all vehicles below about 100,000 pounds, the maximum hook load is due to dynamic tensions through the entire operational speed range, whereas above this weight hydraulic hook loads are most critical.

There was no indication of excessive dynamic loads during the dead load tests; in fact, where dynamic hook loads were critical (50,000 pounds) a Z factor of slightly lower than 2.5 was experienced.

Figures 42 through 45 show that, although the 50,000- pound dead load agrees well with the calculated hydraulic hook load, the higher weight dead loads experienced somewhat lower maximum hydraulic tensions. This proved to be a desirable feature, since results during the aircraft test series showed a rise to good agreement with the peak computed values.

(c) Hook Bounce Tests. An original configuration 17-4 PH Boeing 720 Sheaffer spring hook shank with an aluminum hook point was hung on the side of the dead load during Runs 36 through 55 (see Test Plan 1476-5, Appendix B) to determine the hook bounce characteristics over known obstacles. The aluminum hook point was ballasted to equal the weight (19 pounds) of the new 17-4 PH hook point for the Boeing 720 and the Boeing 707.

The obstacles used were 1-, 2-, 3-, 6-, and 10-foot-long ramps, each 1-1/2 inches high. Hook trajectories, as influenced by the obstacles, were determined by high speed photography and the use of frangible indicators at the ramp crests.

Runs 36 through 41 yielded little quantitative information due to lack of horizontal distance references and low frame speed (64 frames per second). No bounce tests were made during Runs 48 through 52 for the 50,000-pound dead load weights.

A 200-frame-per-second camera speed was used on Runs 40 through 54 with satisfactory resolution. The 64-frame-per-second camera was used again for Run 55 because of the possibility of damage of the more expensive model during an over-design-speed arrestment.

The validity of the results of this test series was limited because of the lack of control of many influences, such as runway smoothness, dead load vertical oscillation, and use of a spring shank of lower spring stiffness than in the current design. Also, selection of speeds at the obstacles could not be controlled, since these obstacles were mounted in the area through which the dead loads were being accelerated toward a target arresting gear engaging velocity.

The test data is used primarily as an indicator rather than for conclusive results on specific values.

Centerline lights of six- and eight-inch diameters were encountered at velocities ranging from 90 to 130 knots. Horizontal distance of hook trajectories, from impact to runway return, varied from 20 to 140 feet. The distance travelled was not solely a dead load velocity function. Hook attitude at impact also affected characteristics.

From the limited results obtained it appears desirable to eliminate projecting runway centerline lights for a distance of 300 feet on the engaging side of the pendant in order to ensure the absence of hook disturbance and thus engagement.

The steel ramps employed were traversed at dead load velocities ranging from 90 to 135 knots. As with the centerline lights, hook stability proved a decisive factor in the action of the hook point on the ramp. Frangible indicators placed at quarter-inch vertical intervals on the ramp crests showed that, in cases where the hook point engaged a ramp with no other motion than that imparted it by the dead load velocity, it rode smoothly along the ramp surface. This action was independent of slope with the configurations used. In a condition where the hook point encountered a ramp with a downward velocity, the resultant upward deflection on impact threw the point clear of the ramp crest. It may be argued that an increase in ramp length will counteract this effect but sufficient evidence has not been acquired on the basis of the tests made to substantiate this assertion.

See Figure 29, Appendix A for specific data during Runs 46 through 55.

(d) Hook Point Impact Test. To determine runway impact effects on the Boeing 720 and 707 tail hook point at maximum impact velocity, the 707 tail hook was dropped while mounted on a bracket attached to the frame of the Model 3500 arresting gear's dead load. This mount, situated 48 inches above the runway surface, represents the distance from the tail hook attachment point on the Boeing 720 and 707 aircraft to the static ground lines. As shown in Appendix B, Test Plan 1476-5, maximum hook point velocity can be derived statically by raising the free end of the tail hook to a height of 77 inches above the runway surface. The resultant over-bend simulates the additive effect of maximum allowable aircraft descent velocity (10 f.p.s.) to the spring hook's inherent free end velocity upon release from stow position while airborne. This maximum attainable velocity was combined with the most critical hook point attitude, i.e., flat sole impact on the runway.

The hook point was raised with a crane and dropped by means of a glider release. A visually plumbed wooden rod, appropriately marked, was used to ascertain the prescribed 77-inch deflection. After several drop cycles the concrete in the immediate impact area developed pronounced cracks due to the severity of the repetitive shock loading. Upon completion of 25 drop cycles, the hook point had worn its face profile into the concrete to a depth of 1/4 inch in places. Subsequent inspection of the hook point disclosed no evidence of failure or deformation.

The existing design of the 720 and 707 hook point proved suitable to withstand the effects of runway impacting under multiple maximum velocity conditions.

B. AIRCRAFT TEST SERIES

The Convair C-131B test aircraft was flown to Georgetown Test Base on 1 October for instrumentation and installation of the arresting hook shank. The arresting hook shank had been made up from a Navy AD tail hook lengthened to 103 inches. This airplane and tail hook had been used for previous feasibility tests under Contract FAA/BRD-37. During these aircraft tests the plane was operated and maintained by Federal Aviation Agency flight personnel. Description of this airplane and the tail hook installation can be found in Bureau of Research and Development Report, PB 161915 (All American Report M-475).

For testing with the Model 3500 arresting gear, a Navy F4D hook point was adapted to the shank and 1-1/2-inch-diameter cable since the original AD shoe provided too small a cable groove diameter and cable bending radius.

Upon completion of instrumentation installation, the airplane was returned to NAFEC and the arresting tests commenced on 8 October 1962. All engagements were made at about 50,000 pounds gross weight. A total of eleven engagements were made in a four-day period, including both on-center and off-center engagements. A tabulation of the results is included in figure 25. There was one instance of missing the arresting wire caused by tail hook bounce. Upon investigation, it was noted that the pneumatic pre-charge recommended (1500 psi) was only 1200 psi. This reduction in pressure affected both the hold-down force on the hook and also the bounce characteristics of the hook, i.e., allowed a longer time for the hook to skip before returning to the runway. The hook actuating cylinder was serviced to 1500 psi and no further misses occurred. All of the engagements were taxi engagements, there being no fly-in tests planned for this plane.

The Boeing 720 N-113 received an installation of a manifold barrel water ballast system at the Boeing plant during the period 8-10 October and was flown to New Castle Airport, Wilmington, on 11 October. The aircraft instrumentation as described in Section III, and the spring tail hook were installed on the plane starting on 12 October and completed 18 October.

The arresting gear engagements started on 19 October 1962, and except for the two demonstrations on 8 and 9 November, the tests were completed on 30 October. All of the tests were taxi-in except for the one on 30 October and the two demonstrations on 8 and 9 November, which were landings with roll-in engagements. Results of the tests are tabulated in figure 26. At no time did the spring hook fail to engage the arresting wire.

(1) Pre-tensioning System. In general the pre-tension system on an arresting gear is used to provide a taut pendant. The pre-tension system serves the following specific functions:

(a) It should provide sufficient height of the pendant between discontinuous pendant supports to provide reliable hook engagements. The allowable spacing of supports is determined, in some measure, by the tension level in order not to experience much catenary sag between supports. The dynamic depression wave generated by the aircraft tires is also a consideration in pendant support spacing.

(b) Provide tension on the pendant to restrict the lateral deflection of the pendant from the support elements from tire impact or afterburner thrust deflection.

(c) On a water squeezer arresting gear to serve as a stop to limit the retrieve travel and aid centering of the cable system.

(d) Release reliably under engagement forces. During the dead load test series, where overhead engagements were accomplished, the pre-tension system was only required to support the cable overhead at a consistent height between stanchions. A modified E-14-1 pre-tension system was used.

Prior to the aircraft test series, a more refined manual operational system was designed and fabricated. It was used for all Boeing 720 tests. It provided an 8000-pound tension level and a 12,000-pound release (double shear on an AN-5 bolt). Tension was applied by means of a cable hoist located in the Station 40 pit (see figure 6). The cable from the hoist was reeved 90° around a sheave just outboard of the deck sheave (figure 5) through a fairlead inboard of the deck sheave to provide double reeving at the shear pin and back to a 1-1/2-inch-diameter nylon rope. The shear pin was connected to a clamp fastened to the arresting gear purchase cable. The nylon rope acts as a spring and serves the function of providing elasticity during wheel roll-over, thus preventing premature shear pin failure.

A spring-loaded drum was located at the slack side of the manual cable hoist to store the excess cable. The hoist was attached to its mounting through a set of die springs and an indicator mark to indicate the proper tension level.

The only minor difficulty experienced was weld failure, after repeated use, of the lug on the rub block attached to the shear pin. A different welding technique was utilized to rectify this malfunction, and no further difficulties were experienced.

(2) Cable Tensions. The dynamic cable tensions measured with the C-131B were lower than those of comparable 50,000-pound dead load shots. This may be seen in comparison of figure 30 with figure 46. However, all cable tensions with this aircraft are much below the allowable working tension for the cable and are not a serious consideration.

Hydraulic cable tension levels were even lower than those due to dynamics and are also considerably lower than in the dead load series. Since the major portion of kinetic energy was absorbed during dynamics and cable drag, the piston dive velocity is very low and therefore subject to great deviations from outside influences such as aerodynamic drag, cable friction, and aircraft brake application.

Maximum dynamic cable tensions with the Boeing 720 at both 135,000 and 220,000 pounds are the same (see figures 47 and 48). The ratio of maximum dynamic tension to theoretical initial impact tension are 1.5 up to about 120 knots when they tend to increase at a higher rate with increasing engaging velocity.

The hydraulic cable tensions experienced with the Boeing 720 at both 135,000 pounds and 220,000 pounds are in excellent correlation with computed values, with some tendency to fall below computed values above 110 knots.

It is interesting to note that there is an increase in hydraulic cable tensions of the 220,000-pound aircraft over that of the 200,000-pound dead load which is probably due to residual thrust effect from the engines.

(3) Hook Load. The C-131B dynamic hook loads followed a Z curve of 2 very closely. Refer to figure 52 for a plot of dynamic hook load versus engaging velocity. These were considerably below those measured with dead loads of comparable weight and permitted an engaging velocity up to 103 knots to reach the 1 g limit.

The peak hydraulic hook loads with the C-131B were of about half the magnitude of peak dynamic hook load and of approximately the same slope rise with increased engaging velocity. They were lower than computed (see figure 55) but of no major significance. It should be noted that the method of hydraulic hook load and cable tension computation does not take into consideration the energy absorbed by dynamics and therefore yields conservative computations at weights well below the maximum design weight. An empirical relationship has been developed to compensate for this error in computing for light weights and is discussed later in Section V.B.

Dynamic hook loads for the Boeing 720 at 135,000 pounds and 220,000 pounds show the rise in Z factor with increasing weight. For 135,000 pounds the Z factor was 2.75 and 3.0 at 220,000 pounds. It is not anticipated that this rise in dynamic hook load will progress beyond about 3.1 or 3.2 through the entire performance range due to the fact that at higher weights there is less significant deceleration throughout the time interval of dynamics.

Maximum hook load at both 135,000 and 220,000 pounds showed good correlation with the computed values of hydraulic hook load. Extrapolation of the

220,000-pound hydraulic hook load curve indicates a limit 220,000 pounds (1 g) hook load at about 138 knots.

Aircraft tests with the Boeing 720 were nominally limited to an applied hook load of 180,000 pounds because this was the fuselage proof loading limit, although the design load was 225,000 pounds.

Figure 58 shows the characteristic difference in hook load curve shapes for a light and heavier weight aircraft.

(4) General Hook Performance

(a) C-131B. The C-131B hook installation performed satisfactorily except for minor damage incurred by the shank to a camera port directly above the hook point fitting and aft of the hook bumper. Figure 18 shows the camera window which was broken by the uppermost portion of the hook point fitting during impact and elastic deformation of the bumper. This photograph also shows slight damage to the window frame. Note the stretch of the stainless steel strap due to repetitive deformation of the hard rubber bumper member.

Study of high speed photographs taken from a camera mounted on the aircraft revealed that the reflected kink wave, upon reaching the hook, causes a vertical acceleration of the shank prior to stabilization of the loads which maintains the shank below the bumper.

The sponge rubber wrapping around the shank shown in figure 19 was the first attempt to keep the shank from the skin line. However, the sponge rubber was not hard enough and did not add sufficient thickness to eliminate the problem.

Two additional layers of hard rubber strip were added to the bumper, one between the original rubber and the stainless strip and a second below the stainless strip. This added approximately one inch to the undeflected bumper height. Figure 20 shows this modification.

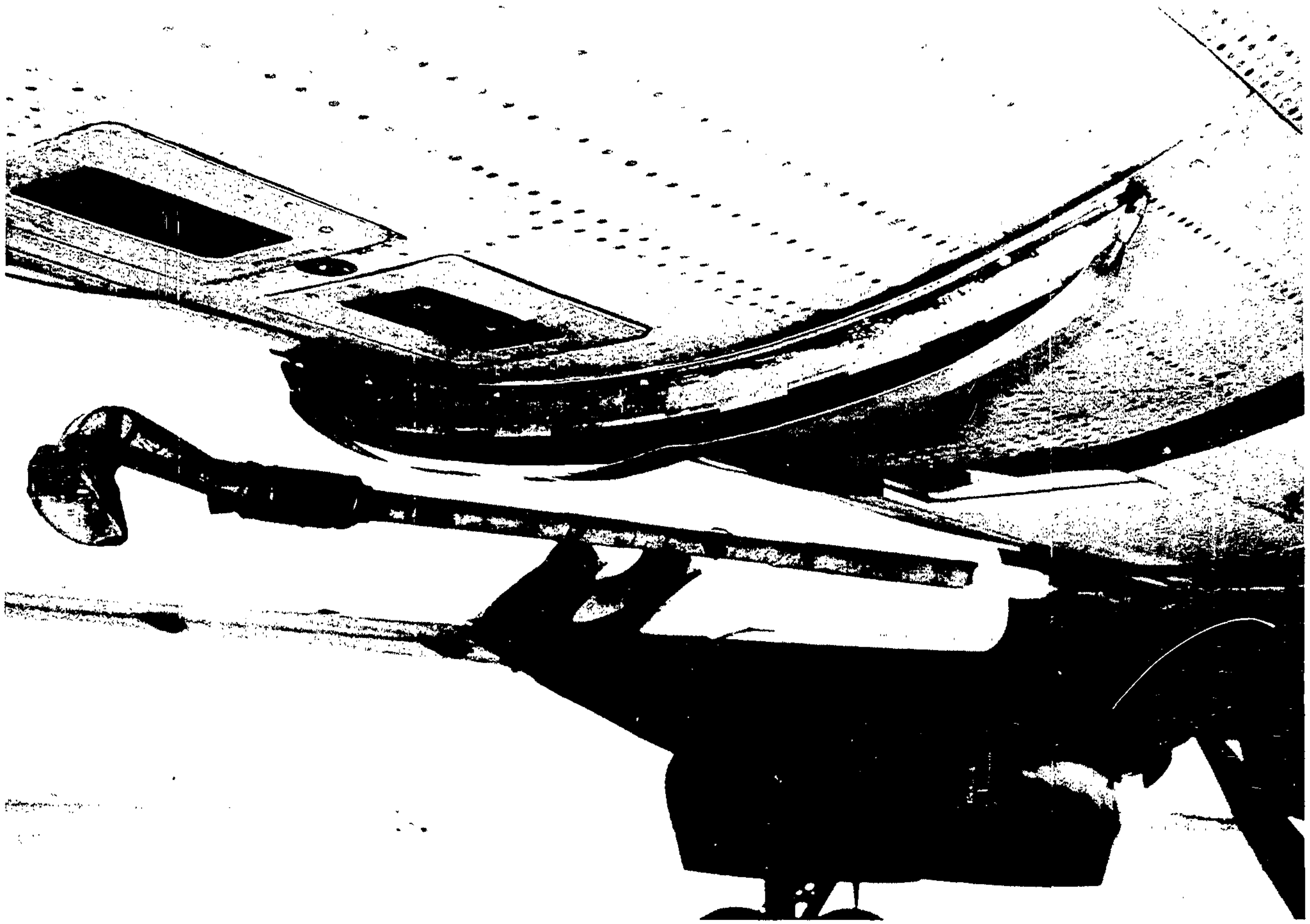


Figure 19 C-131B Tail Hook and Original Bumper Installation

No further difficulty was experienced; however, it is believed that a more practical solution would be to utilize a means whereby the shank load on the bumper is better distributed laterally throughout the bumper surface rather than have localized high bearing pressures and resultant high deflections. Distribution of bumper load could possibly be achieved by the use of cord impregnated in the rubber or a sandwich construction bumper material. The lateral distribution would probably reduce the required bumper thickness.

Internal snubbing at the hold-down cylinder to counteract this problem would cause excessive shank bending and would require much added weight for adequate strength. A spring shank similar to that used for the Boeing 720 has better characteristics due to its lower mass moment of inertia.

(b) Boeing 720-027. The Boeing 720 and 707 spring hook performed satisfactorily as anticipated with no missed engagements or failures throughout the 30 arrestments. The first Boeing 720 shank was used for Runs 1 through 10, the second 720 shank for Runs 11 through 21, and the Boeing 707 shank for the last 9 runs. No difficulties were experienced with the hook point during the aircraft testing. The maximum cable transfer through the shank was 21 feet, resulting in no damage to deck pendants or shoes. The shoes and shanks were changed after approximately 10 arrests.

The two Boeing 720 shanks showed some permanent bending distortion about the horizontal axis in the shank area immediately adjacent to the hook point fitting for a length of approximately sixteen inches. This is due to the dynamic wave action of the shank end during the cable engagement and early dynamic portion of arrestment. This distortion appeared to have no effect on the functioning of the shank.

Figure 21 shows this distortion against a loft board. A metallurgical investigation was carried out to determine if the yielding has had any serious effect on the structural integrity of the shank.

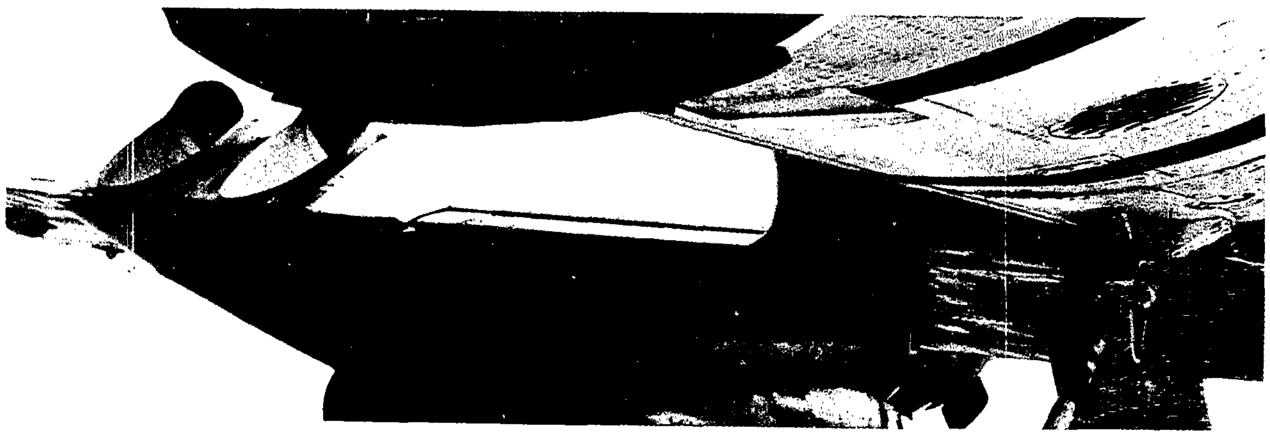


Figure 20 Modified C-131B Tail Hook Bumper

Three longitudinal and three transverse sections were prepared for tensile specimens. The following code is used to evaluate figure 28, the tabular results.

TN - transverse specimen from undeformed section at mid-length of shank

TY - transverse specimen from yielded section adjacent to hook point fitting

LN - longitudinal specimen from undeformed section at mid-length of shank

LY - longitudinal specimen from yielded section adjacent to hook point fitting

A hardness survey revealed excellent consistency of the specimens. Yield values from the deformed specimens show some increase over the undeformed section. This was due to the high working stress at this section and revealed a change in shape for the stress-strain curves.

This yielding or cold working resulted in raising the elastic limit and improving the fatigue strength but ultimately reducing its cyclic fatigue life.

Micro-structure examination at 100 × and 500 × showed typical martensitic grain structure of SAE 4340 steel with 0.005 inch decarburization.

The shank intended for the Boeing 707 showed no yielding after nine arrestments on the Boeing 720 aircraft. Of course, this shank was not subjected to the limit loads for the 707 aircraft, although it did realize the same wave phenomena during cable dynamics.

In the interests of standardization, ease of fabrication, and superior performance, it appears desirable to use maraging stainless steel shank for both the Boeing 720 and 707 aircraft.

There was a recurrence of minor skin damage to the aircraft adjacent to the shank as had been experienced during previous tests at NATF, Lakehurst, N.J., as described in AAE Report M-657A. This damage was noted after repetitive loading, and consisted of two types. The first was a compression wrinkle in the skin in the area immediately aft of the shank-attaching fitting at Station 960. This was caused by frame deflection at the aft side of the fitting. The second type of

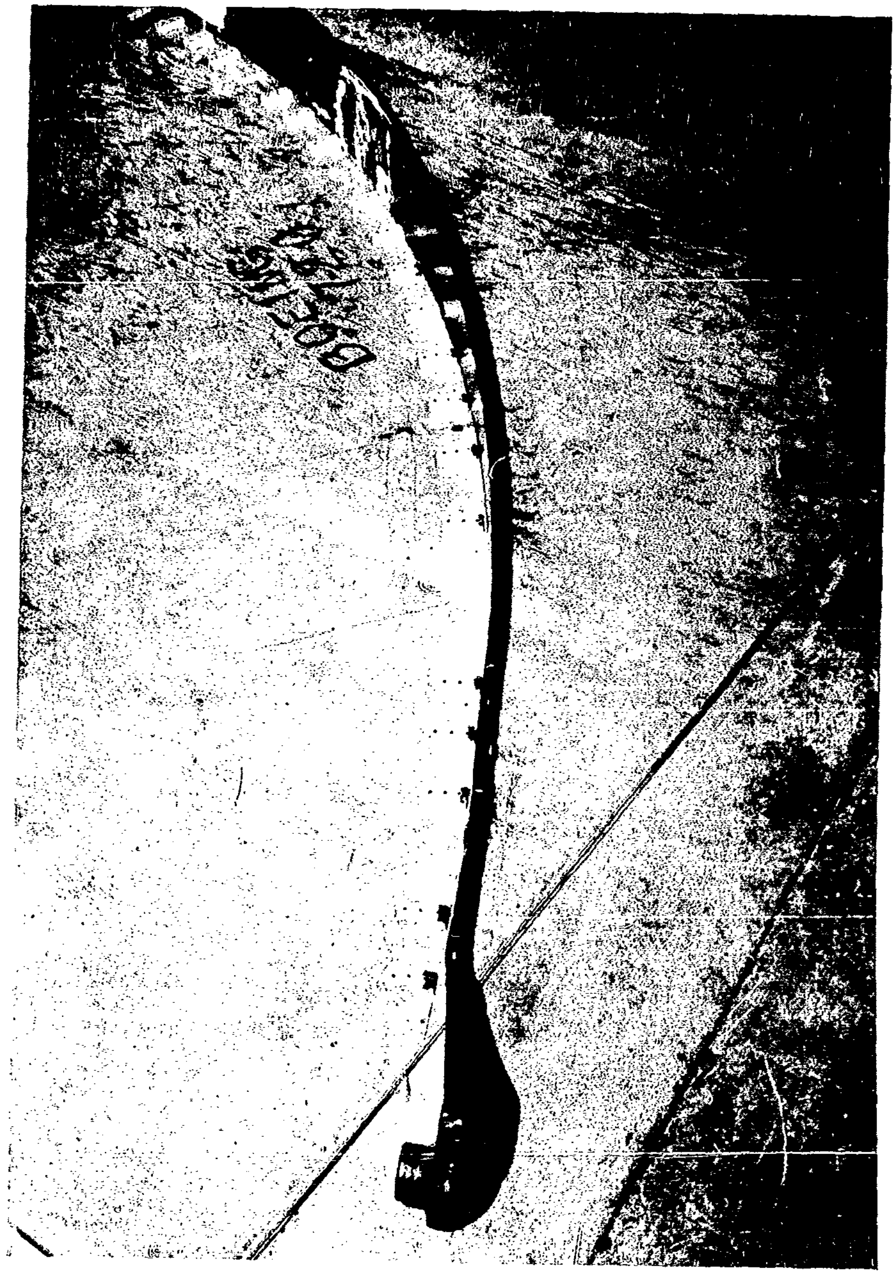


Figure 21 Deformed Boeing 720 Spring Shank Against Loft Board

damage was an inward bowing of the skin between three successive frames and bounded laterally by the center stringers at an area about mid-length of the shank. This caused shear of five rivets which connect the frame at Station 1080 to a clip angle extending to the skin between the center stringers. These were replaced by screws during the testing and subsequently replaced with bolts during instrumentation removal along with a frame repair prior to Runs 29 and 30. This repair is shown in AAE sketch 12SK671.

The compression wrinkle was straightened and rivets around the vent duct were replaced prior to Runs 29 and 30 in preparation for flight to Oklahoma City.

The skin deformation under the shank midpoint is caused by the wave phenomenon of the shank immediately after cable engagement. The shank bears on the skin, causing permanent stretch. The skin deformation was of such a small degree as to not require skin replacement. For repetitive arrestments it would be necessary to strengthen this skin area internally. Any external overlay to the existing skin line would probably show no improvement because of reduced clearance between the hook shank and skin, possibly resulting in greater damage.

(c) Hook Rotation in Yaw. Figure 27 shows the reduced hook yaw angle data. During both the C-131B and Boeing 720 tests, hook shank yaw angle with respect to the longitudinal aircraft centerline was continuously measured during the arrestments. This was to determine the direction of hook load application in order to correlate strain gage information on the structure and also to verify the 10-degree yaw hook load design criteria used for both hook installations. Figures 25 and 26 show the maximum hook angles experienced during each run. However, it is also pertinent to study the time plot of hook angle and tension. Figures 59 and 60 are two typical off-center runs of yaw angle versus time. Figure 59 and 61 are for the same run but Figure 61 is plotted versus runout rather than time.

In every case the maximum yaw angle of the hook occurs early in the arresting cycle, i.e., during dynamic hook load. The shank also tends to oscillate about the centerline and finally converges to or very near the aircraft centerline, depending upon the off-center engaging distance.

The hook shank has attained a yaw angle greater than 10 degrees for both aircraft (18.7 degrees for C-131 and 19.7 degrees for Boeing 720) but not concurrently with maximum hook load. When the hook load builds up, the hook seeks a nearly central location, and therefore limit design loads are exerted well within the 10-degree design yaw angle.

The Boeing 720, even at the lightest operating weight of 135,000 pounds, was subject to peak hook loads after piston dive into the fluid. This resulted in a large time increment occurring between maximum hook yaw angle and maximum hook load.

The C-131B, however, was subjected to maximum hook load during the same time interval (dynamics) as the hook was stabilizing in yaw. However, concurrent peaks are not likely to ever occur as long as cable transfer through the hook point is not restricted. A hard, non-seizing hook point throat ensures free transfer of the cable and precludes high asymmetrical loading.

It appears that a 10-degree yaw load application at design hook load is a safe, reliable design condition with this arresting gear through 60-foot off-center engagements.

Provision for unrestrained hook rotation through at least 20 degrees to both sides of the aircraft centerline is desirable.

(5) General Arresting Gear Performance. The Model 3500 arresting gear proved to have outstanding reliability throughout the dead load and aircraft test series. In no case did the arresting gear fail to stop the vehicles except on one occasion of hook point failure during the dead load series. In 95 arrestments no failures occurred on the arresting gear which would have endangered lives had all of them been emergency aircraft arrestments. This is indeed an unusual record for an arresting gear under development.

The arresting gear has been demonstrated at off-center engaging distances through sixty feet with no detriment in performance, either in arresting gear or aircraft loads and runout characteristics. Undoubtedly, additional off-center engaging potential exists which is as yet uninvestigated.

Retrieve operations for the Model 3500 proceeded without incident except for one case during the aircraft program and a few during the dead load program when the retrieve ropes failed due to continued use after exceeding the recommended wear criteria (see All American Engineering Handbook SM-208). No failures of the retrieve ropes occurred in the final configuration due to abrasion when the ropes were replaced without exceeding 10 arrestments. A thimble guard added during the program and intended to prevent accelerated fraying of the rope at the end adjacent to the piston was found undesirable since it was deformed by impact with the tube walls and caused cutting. The substitution of an extra heavy thimble for the original standard weight thimble protects the rope adequately without subjecting it to cutting by the guard.

The time for recycling the arresting gear averaged between an hour and an hour and a half during the aircraft tests. Usually the retrieve ropes were refaked during this recycle time. This would not normally be done, but rather a set of previously faked ropes inserted and the used ones removed for faking at leisure off of the runway. This time is subject to variation by crew indoctrination, weather, etc. However, it should be noted that a runway can be cleared for operation without the gear in about five minutes by disconnecting the pendant on one side and pulling the cable off the runway surface.

The arresting gear could be recycled with a minimum of one truck and three men; however two trucks and five to seven men is recommended for expediency.

Extrapolation of all cable tension and hook load data through the maximum kinetic energy condition (350,000 pounds at 130 knots) indicates the gear has sufficient energy absorbing capacity.

After Run 29 with the Boeing 720, lay distortion of the purchase cables near the piston was noted. This lay distortion was caused by the strands not returning to their original orientation in the rope during dynamic loading. Although the aircraft arrest was normal, difficulty was experienced in retrieving the distorted area through the split bushing, requiring another purchase cable replacement on the port side. The cables were installed after Run 28 during a delay in testing before a demonstration program. It is known that certain peculiarities in wire rope construction, such as gap between adjacent strands, make the wire rope more vulnerable to lay distortion. Visual examination of this wire rope revealed no excessive gap between strands in the undistorted area, however.

This was the only case of lay distortion in 96 arrests. One occurrence of this difficulty, under circumstances similar to that experienced during the dead load program, lead to the conclusion that this may have been an unusual occurrence attributed to wire rope construction. No changes are indicated unless there is a repetition of this difficulty.

A permanent set of the purchase cables into a mild helical shape in the area one to two hundred feet adjacent to the piston is frequently observed in used purchase cables. This mild helix causes no difficulty and does not compromise the integrity of the arresting system.

On the Model 3500 arresting gear at NAFEC, rapid wear of the sheave rub-blocks was experienced. These are mild carbon steel plates located on the deck sheave mounting plates to guide the cable into the deck sheave after rising from its line inside the tube below ground. The rapid wear of these rub-blocks was due to the relatively deep installation of the arresting tube and resultant high induced cable load normal to the block surface. The gear was located against the existing topographical slope to facilitate installation of the test installation at reduced cost and airport interference. An operational gear usually is installed so that a shallower tube is required. The arresting gear at Georgetown was shallower and reduced block wear was experienced.

On Boeing 720 Run 30, two unchamfered rub-blocks were put into the gear in error and resulted in several broken wires adjacent to the rub-block upon cable engagement due to cutting. This would not happen during normal operation due to the rounded profile of the standard part.

Figure 62 shows representative runout distance curves for each of the weights tested. The runout distances for similar weights of aircraft and dead load showed excellent correlation for the same engaging speed.

(6) Performance Envelopes. Although the Model 3500 arresting gear has not been tested to its maximum design energy capacity, the analysis of the data gathered to date permits reliable extrapolation through and beyond the design limits. The full design specification weight range has been tested, and the maximum design specification engaging speed has been exceeded both with aircraft and dead loads. Both cable tension and hook load data accumulated to date are orderly, and extrapolation is reliable since it substantiates the calculated performance.

In the performance of a hydraulic energy absorber designed for a specific maximum weight and engaging velocity there is an inherent over-design-weight tolerance at a decreased engaging velocity. The limitation on these heavy weight arrestments is the safe working tension on the cable (66 percent of minimum guaranteed breaking strength). Figure 63 shows the potential over-specification weight capability based upon computer runs. This high weight potential continues beyond 450,000 pounds; however this range covers the weight of all present civil and military aircraft.

The limitation in speed for weights below 350,000 pounds as shown in figure 63 is based upon a limiting hook load of 1 g, either generated by hydraulic or dynamic forces. It may be seen that a 1-g hook load is anticipated at 290,000 pounds and about 141 knots without exceeding the safe working load of the cable.

Aircraft weights below 50,000 pounds are tolerable at reduced engaging velocities with the 1-g limit.

Figure 64 is a plot of the mean hook load in terms of g's anticipated with the

Model 3500. It is evident from this plot that it is not reasonable to establish an arbitrary 1-g limit for all weight aircraft to gain maximum utility from this arresting gear. This is characteristic of most all arresting gears. Lighter weight aircraft require a higher g hook strength than heavier ones in order to have the same speed potential. Of course, this upper deceleration limit is based upon the tolerance of the entire aircraft structure and passenger safety and comfort. Even a slight increase in allowable hook load increases the speed potential of lighter aircraft for arrestment. The increase in allowable hook load over 1 g for lighter aircraft may very well permit the utilization of one arresting gear, without the requirement for a variable control, through all operational speed requirements.

For infrequent emergency use it is worthwhile to consider exceeding sixty-six percent of minimum guaranteed cable breaking strength. It is a small penalty to replace a set of arresting cables or even minor aircraft structural damage in order to save a modern jet aircraft and its passengers. In order to accomplish repetitive high velocity arrestments with heavy aircraft, a considerable penalty is usually paid in light weight aircraft arresting capability.

At reduced weights the Model 3500 may have a velocity potential as high as 180 knots. Testing would be necessary to verify the tolerance of the arresting gear hardware to these high engaging velocities. Successful arrestments have been made by similar but smaller scale water squeezers at 180 knots. Repetitive use at these velocities has not been demonstrated and is beyond the present state of the art.

VI CONCLUSIONS

(1) The Model 3500 arresting gear is capable of stopping civil aircraft of the weights and speeds used in the tests in less than 2000 feet without exceeding aircraft strength or providing discomfort to the passengers.

(2) The dead load and aircraft tests show satisfactory arresting gear performance through the weights and speeds tested.

(3) The arresting gear was not tested to maximum design energy capacity, but extrapolation of quantitative data accumulated from dead load and aircraft tests indicates satisfactory arresting gear performance for weights and speeds specified in the contract.

(4) The Boeing 720 Sheaffer spring hook installation demonstrated dependable engagement and arrestment capability through maximum aircraft gross weight and 135 knots at off-center distances through 60 feet with minor skin damage to aircraft.

(5) The Convair C-131B can be arrested at 50,000 pounds weight and up to 103 knots velocity without exceeding the 1-g hook load.

(6) Off-center arrestments can be made at 60 feet to either side of the runway centerline without exceeding cable tensions or hook loads generated on center.

(7) Hook bounce tests indicate that the semi-flush centerline lighting within 300 feet of the pendant will cause hook bounce and uncertain engagement of the pendant. Further tests are required to determine specific effects of pavement irregularities and obstacles on the hook when extended for engagement.

APPENDIX A

TEST DATA

EVENT NO. A.G.	EVENT NO. CAT.	TEST DATE	DEADLOAD WEIGHT	ENGINE RPM, %	REQ'D A/G ENG. VEL.	PREDICTED ROLLDOWN	59° POWER CUT-OFF	59° POWER CUT-OFF	TEMP / P_{ATM}	THROTTLE ADVANCE TIME	CALC. D/L VEL. AT CUT-OFF	HYD./AIR PRESS IN ACCUMULATOR	A/G ENGAGING VELOCITY	REMARKS
			(POUNDS)	THEOR/ACT.	(KNOTS)	(KNOTS)	(FEET)	(STATION)	°F / IN. HG	SECONDS	FT/SEC.	P.S.I.	KNOTS	
1	1	4/3/62	50,000	70/N.R.	40	10	N.R.	N.R.	N.R./N.R.	6	N.R.	1275/1000	57.8	
1a	2	4/6/62		75/N.R.	80	8	1750	1125	66/30.35	6	149	" "	ABORT -	CABLE SLIPPED THRU JAWS
2	3	4/19/62		75/N.R.	80	8	"	"	52/29.91	6	"	" "	82.7	
3	4	4/23/62		75/75	80	8	"	"	79/29.92	6	"	" "	84.5	
4	5	4/23/62		80/80	100	6	1,990	1,365	70/29.75	6	179	" "	100.2	
5	6	4/24/62		85/84	110	4	1,425	800	63/30.09	6	193	1290/1000	84.5	PARTIAL ABORT - CROSSHEAD OSCILLATING
6	7	4/26/62	200,700	75/74	40	8	1,200	575	85/30.00	6	81	1275/1000	43.2	
6a	8	4/27/62		85/N.R.	80	2	2,277	1652	83/30.00	6	139	950/1000	ABORT	CROSSHEAD SLID AT CAPSTAN.
7	9	5/14/62		75/75	40	8	1,200	N.R.	72/30.16	10	81	1275/100	25.0	VELOCITY INDICATOR READ HIGH.
8	10	5/15/62		80/76	60	5	1430	N.R.	80/30.84	10	110	1250/1000	67.3	
9	11	5/15/62		85/82	80	3	2,290	1,665	80/30.13	10	140	1680/1000	81.7	
10	12	5/16/62		90/88	98	2	2,600	1,975	65/30.28	10	169	1720/960	96.5	
11	13	5/16/62		92/91	100	3	"	"	68/30.28	10	174	" "	103.0	
11a	14	5/17/62		92/90	116	2	3,250	2,625	66/30.25	10	199	1875/1000	ABORT.	VISUAL INDICATION OF LOW HYD. PRESS. IN COMPENSATOR
12	15	5/18/62		93/90	116	2	"	"	81/30.06	15	"	1845/1480	116	
13	16	5/18/62		93/92	122	1	3,453	N.R.	87/30.28	12	208	" "	118.5	
14	17	5/21/62		96/96	128	1	3,480	2,855	86/29.77	15	218	1845/1500	127.5	
15	18	5/21/62		98/97	130	1	3,222	N.R.	86/29.75	15	220	1875/1570	131.8	
16	19	5/23/62	300,900	90/92	80	3	1,984	1,359	80/30.00	15	140	1845/1525	84.5	
17	20	5/24/62		95/95	100	2	2,590	1,865	78/29.82	15	172	1875/1570	102.9	
18	21	5/24/62		96/96	100	2	"	"	84/29.82	15	"	" "	103.0	
19	22	5/25/62		97/97	115	1	3,220	2,595	79/29.88	15	196	1900/1570	115.0	
20	23	5/25/62		97/97	115	1	"	"	82/29.88	15	"	" "	114.0	
21	24	5/28/62		98/97	120	1	3,380	2,755	65/30.16	15	204	1925/1600	116.1	BATTERY AT -425
22	25	5/31/62		100/100	120	1	3,260	2,835	69/30.07	20	204	1975/1600	120.7	" " "
23	26	6/2/62		100/100	120	1	"	"	84/29.92	20	204	" "	119.5	" " "
24	27	6/12/62	350,920	85/84	60	4	1,787	1,362	74/29.92	20	108	1975/1600	66.3	BATTERY AT -425
25	28	6/12/62		94/94	80	2	2,281	1,856	76/29.80	20	138	" "	81.7	
26	29	6/13/62		95/96	100	2	2,993	2,568	62/28.31	20	172	" "	103.0	
27	30	6/14/62		95/95	90	2	2,441	2,016	65/N.R.	20	155	" "	91.2	
28	31	6/21/62		96/97	100+	2	3,041	2,616	80/29.80	20	172	" "	103.0	
29	32	6/22/62		98/97	110	1.5	3,246	2,821	74/29.99	20	188	" "	105.7	

Figure 22 Launcher Master Data Sheet (Sheet 1 of 2)

EVENT NO. A.G	/ CAT.	TEST DATE	DEADLOAD WEIGHT (POUNDS)	ENGINE R.P.M. % THEOR./ACT.	REQ'D A/G ENG. VEL. KNOTS	PREDICTED ROLL DOWN KNOTS	59° POWER CUT-OFF FEET	59° POWER CUT-OFF STATION	TEMP °F / PATM. IN. HG	THROTTLE ADVANCE TIME SECONDS	CALC D/L VEL. AT CUT-OFF FT/SEC	HYD./AIR PRESS. IN ACCUMULATOR P.S.I.	A/G ENGAGING VELOCITY KNOTS	REMARKS
30	33	6/25/62	350,920	100/99	MAX.	N.R.	3240	2815	84/29.86	20	195	1975/1600	113.0	
31	34	8/8/62	200,700	98/96	125	1	2,940	2,815	84/29.82	20	212	1975/1600	41.0	AIR PRESSURE ON JAWS
32	35	8/10/62		96/96	125	1	2,957	2,332	65/29.99	"	"	" "	121.0	
33	36	8/11/62		100/96+	130	1	3,243	2,618	N.R./N.R.	30	220	1975/1600	129.9	
34	37	8/13/62		100/97.6	130	1	3,255	2,630	78/29.98	20	"		130.3	
35	38	8/22/62		100/98.8	130	1	3,217	2,592	82/28.98		"		131.6	
36	39	9/5/62		92/91.8	108	2	2,903	2,278	80/29.95		186		107.6	
37	40	9/6/62		94/N.R.	115	2	2,966	2,341	70/N.R.		108		116.0	
38	41	9/7/62		97/N.R.	120	2	N.R.	N.R.	N.R./N.R.		206		119.2	
39	42	9/18/62		97/N.R.	120	2	2,815	2,190	73/N.R.		"		119.5	
40	43	9/20/62		85/N.R.	85	3	2,589	1,964	75/N.R.		149		84.1	
41	44	9/20/62		90/N.R.	90	3	2,099	1,474	65/N.R.		157		91.1	
42	45	9/21/62		87/N.R.	95	2	2,451	1,826	62/N.R.		164		93.2	
43	46	9/22/62		88/90.1	100	2	2,689	2,064	62/30.25		172		100.2	
44	47	9/24/62		89/90.8	105	1	2,727	2,102	66/30.12		179		103.8	
45	48	9/24/62		92/92.8	110	1	2,815	2,190	73/30.18		188		110.9	
46	49	9/25/62		94/94	115	1	2,891	2,266	67/29.92		196		114.9	
47	50	9/26/62		96/95.8	120	1	2,903	2,278	65/29.90		205		119.6	
48	51	9/27/62	50,000	75/75.5	85	3	2,702	2,077	62/29.50	20	149	1975/1600	88.9	
49	52	9/27/62		75/75.1	85	3	2,476	1,851	65/29.50		"		84.0	
50	53	9/28/62		80/79.3	100	2	2,388	1,763	63/29.62		172		97.8	
51	54	9/28/62		80/79.5	100	2	2,589	1,964	70/29.62		"		100.2	
52	55	9/29/62		80/79.5	100	2	2,514	1,889	65/29.92		"		100.2	
53	56	10/2/62	300,000	100/99.6	120	1	3,305	2,680	72/30.18		205		119.2	
54	57	10/3/62	"	100/99.6	120	1	3268	2,643	67/30.19		"		119.8	
55	58	10/3/62	200,000	100/98.1	134	1	3,456	2,831	68/30.13	20	228	1975/1600	135.5	

Figure 22 Launcher Master Data Sheet (Sheet 2 of 2)

RUN NO.	TEST DATE	DEADLOAD WEIGHT	ENGAGING VELOCITY	DEADLOAD RUNOUT	MAX. DYNAMIC CABLE TENSION PORT	MAX. DYNAMIC CABLE TENSION STBD.	MAX. HYDRAULIC CABLE TENSION PORT	MAX. HYDRAULIC CABLE TENSION STBD.	MAX HOOK LOAD DYN.	MAX HOOK LOAD HYD.	MAX F+A. DECEL.	MAX TUBE PRESSURE		REMARKS
		(POUNDS)	(KNOTS)	(FEET)	(POUNDS)		(POUNDS)		(POUNDS)		(g's)	(P.S.I.)		
1	4/3/62	50,000	57.8	765	22,800	21,100	6160	6,600	38,200	35,700	0.6	290		
2	4/19/62		82.7	883	41,600	42,100	14,740	15,300	36,700	23,200	0.7	865		
3	4/23/62		84.5	949	44,900	44,600	14,500	16,300	34,500	24,000	0.9	833		
4	4/23/62		100.2	1006	56,300	54,950	18,900	19,600	56,000	27,400	1.1	1050		
5	4/24/62		84.5	958	44,400	45,800	15,100	16,020	45,400	28,000	1.0	980		
6	4/26/62	200,700	43.2	1207	17,650	18,030	11,060	12,000	N.R.	N.R.	N.R.	190		
7	5/14/62		25.0	660	N.R.	9,100	N.R.	7,500	N.R.	N.R.	N.R.	42		
8	5/15/62		67.3	1475		36,600		26,400	64,500	62,800	0.5	1000		
9	5/15/62		81.7	1507		45,400		36,800	90,600	83,700	0.6	1310		
10	5/16/62		96.5	1553		52,700		56,400	85,500	108,500	0.8	1645		
11	5/16/62		103.0	1579		62,800		56,800	80,000	109,100	0.7	1630		
12	5/18/62		N.R.	1633		N.R.		N.R.	N.R.	N.R.	N.R.	N.R.		APPROX. 116 Kn
13	5/18/62		118.5	1626		77,900		69,200	114,000	129,800	0.7	2360		
14	5/21/62		127.5	1643		86,600		80,700	120,600	144,100	N.R.	2380		
15	5/21/62		131.8	1668		86,600		79,600	159,000	140,000	0.8	2530		
16	5/23/62	300,900	85.3	1657	N.R.	48,200	N.R.	53,500	73,700	108,500	0.6	1610		
17	5/24/62		103.0	1686		64,300		73,000	69,800	138,200	N.R.	2130		
18	5/24/62		105.0	1693		54,700		73,800	80,700	140,000	0.7	2640		
19	5/24/62		115.0	1709		N.R.		87,600	93,300	175,100	0.4	2910		
20	5/25/62		114.0	1720		77,300		90,300	N.R.	N.R.	N.R.	2940		
21	5/28/62		116.1	1731		68,100		89,400	103,900	173,200	0.6	2700		
22	5/31/62		120.7	1732		77,100		99,000	106,000	178,800	0.7	2880		
23	6/2/62		119.5	1726		69,400		88,700	101,500	174,000	0.7	3020		
24	6/12/62	350,920	66.3	1701	N.R.	27,800	N.R.	30,400	64,900	73,900	0.3	1110		
25	6/12/62		81.7	1730		39,900		47,300	76,600	99,500	0.3	2420		
26	6/13/62		103.0	1745		64,700		89,400	74,100	141,600	0.4	2400		
27	6/14/62		91.2	1741		47,100		65,200	79,800	136,000	0.6	1810		
28	6/21/62		103.0	1758		56,200		75,900	105,900	127,900	0.5	2070		
29	6/22/62		107.6	1766		60,600		84,100	125,000	168,500	0.6	3190		
30	6/25/62		113.0	1774		64,700		102,600	135,200	180,000	0.4	2680		

Figure 23 Model 3500 Arresting Gear Data, On-center Tests

RUN NO.	TEST DATE	DEADLOAD WEIGHT (LBS)	ENGAGING VELOCITY (KNOTS)	DISTANCE FROM ℄ (FEET)	DEADLOAD RUNOUT (FEET)	MAX DYNAMIC CABLE TENSION (POUNDS) PORT	STBD.	MAX HYDRAULIC CABLE TENSION (POUNDS) PORT	STBD.	MAX HOOK LOAD (POUNDS) DYN.	HYD.	MAX F+A. DECEL. (g's)	MAX TUBE PRESSURE (P.S.I.)	REMARKS
31	8/8/62	200,700	41.0	20	1193	N.R.	N.R.	N.R.	N.R.	N.R.	N.R.	N.R.	N.R.	
32	8/10/62		121.0		1660	70,500	68,700	63,300	65,200	156,600	149,000	0.8	1,850	
33	8/11/62		129.9		1671	76,500	77,900	70,600	73,900	146,800	143,000	0.7	2,270	
34	8/13/62		130.3		1696	80,600	78,300	73,000	75,300	169,000	161,000	1.2	2,430	
35	8/22/62		131.6		1693	79,500	83,000	75,400	78,900	150,300	144,100	0.9	1,990	
36	9/5/62	200,700	107.6	40	1570	54,200	60,900	58,800	62,500	N.R.	N.R.	0.7	2,175	SPRING HOOK
37	9/6/62		115.8		1595	64,000	74,800	66,900	74,800	68,000	136,900	0.8	2,440	
38	9/7/62		119.2		N.R.	62,000	68,900	N.R.	N.R.	66,400	N.R.	N.R.	N.R.	
39	9/18/62		119.5		1615	66,000	66,250	67,000	69,000	74,500	144,000	0.6	2,600	
40	9/20/62	200,700	84.1	60	1520	39,200	42,800	30,600	34,000	49,600	64,800	0.8	1460	SPRING HOOK
41	9/20/62		91.1		1548	45,800	44,000	48,700	53,000	47,500	96,500	0.6	2675	
42	9/21/62		93.2		1560	48,700	49,000	44,900	53,000	N.R.	N.R.	N.R.	2565	
43	9/22/62		101.0		1580	49,600	50,500	43,000	51,000	60,500	93,250	0.7	2700	
44	9/24/62		103.8		1590	56,350	69,100	48,700	49,000	59,300	102,800	0.8	2045	
45	9/24/62		111.6		1606	63,000	76,000	56,350	67,700	69,500	121,100	1.2	2700	
46	9/25/62		114.8		1615	73,500	83,500	61,400	69,000	73,500	128,300	0.8	3280	
47	9/26/62		119.5		1622	75,400	61,600	87,100	72,000	84,800	135,600	0.8	2370	
48	9/27/62	50,000	88.9	60	986	42,000	43,500	10,500	11,360	N.R.	N.R.	N.R.	350	
49	9/27/62		84.0		958	40,100	43,900	13,400	11,350	30,300	23,000	0.8	805	
50	9/28/62		97.8		1010	48,700	58,700	11,460	36,000	N.R.	N.R.	1.0	1110	
51	9/28/62		100.2		1026	51,500	56,800	12,300	35,000	51,300	38,500	1.0	1045	
52	9/29/62		100.2	20	1072	54,400	57,800	10,500	28,400	66,300	N.R.	0.5	1020	
53	10/1/62	300,000	119.2	20	1740	78,300	77,000	76,400	77,000	137,000	234,900	0.5	2,370	SPRING HOOK
54	10/2/62	"	119.8	60	1688	78,400	90,700	83,700	86,200	141,000	N.R.	0.5	3,915	" "
55	10/2/62	200,000	135.4	ON ℄	1715	86,900	83,300	77,300	71,900	140,300	211,400	0.8	3045	SPRING HOOK

Figure 24 Model 3500 Arresting Gear Data, Off-center Tests

RUN NO	TEST DATE	ENGAGING VELOCITY (KNOTS)	RUNOUT (FEET)	AIRCRAFT WEIGHT (LBS)	DISTANCE FROM ℄ (FEET)	MAX. DYNAMIC CABLE TENSION (POUNDS) PORT	STBD.	MAX HYDRAULIC CABLE TENSION (POUNDS) PORT	STBD	MAX HOOK LOAD (POUNDS) DYN.	HYD	MAX TUBE PRESSURE (P.S.I.)	MAX F + A DECEL. (g's)	MAX HOOK DEFL. YAW PLANE (DEGREES)
1	10/8/62	85.2	998	50,000	ON ℄	42,800	39,500	8750	6,900	N.R.	N.R.	495	0.7	2.4
2	10/8/62	87.1	996			41,100	38,800	8700	6,000	39,900	15,900	580	0.7	7.5
3	10/8/62	81.2	980			39,800	36,000	7,900	6,300	N.R.	N.R.	410	0.7	11.5
4	10/9/62	91.8	1007			N.R.	41,300	N.R.	7,400	43,000	18,700	N.R.	0.8	4.9
5	10/9/62	90.5	1008			N.R.	42,500	N.R.	7,700	37,400	18,100	N.R.	0.8	10.0
6	10/10/62	98.5	1035			47,200	N.R.	8,700	N.R.	45,900	N.R.	N.R.	0.9	12.5
7	10/10/62	84.3	1024	50,000	20	36,300	N.R.	9200	N.R.	33,800	17,800	N.R.	0.7	18.7
8	10/10/62	103.8	1040	"	"	42,900	N.R.	9,500	N.R.	50,700	24,100	665	1.0	11.2
9	10/10/62	77.4	950	50,000	40	33,500	32,400	5,100	4,900	36,900	12,900	300	0.7	10.9
10	10/11/62	N.R.	993	"	"	N.R.	N.R.	N.R.	N.R.	44,000	N.R.	330	0.9	15.8
11	10/11/62	89.6	1004	"	"	41,900	41,100	8,800	7,900	44,300	18,600	410	0.8	17.6

Figure 25 Model 3500 Arresting Gear Data, C-131B Arrestment Data

RUN NO	TEST DATE	ENGAGING VELOCITY (KNOTS)	RUNOUT (FEET)	AIRCRAFT WEIGHT (POUNDS)	DISTANCE FROM ℄ (FEET)	MAX. DYNAMIC CABLE TENSION (POUNDS) PORT	STBD.	MAX. HYDRAULIC CABLE TENSION (POUNDS) PORT	STBD.	MAX HOOK LOAD (POUNDS) DYN.	HYD.	MAX TUBE PRESSURE (PSI.)	MAX F+A. DECEL. (G'S)	MAX HOOK DEFL YAW PLANE (DEGREES)	REMARKS
1	10/19/62	80.8	1365	135,000	ON ℄	36,400	35,500	28,700	23,300	46,000	66,200	1340	0.3	6.1	
2	10/19/62	120.8	1355			75,200	70,500	68,900	53,500	N.R.	N.R.	2360	1.1	3.5	
3	10/19/62	106.5	1405			52,300	50,500	48,500	41,900	72,000	96,300	2420	0.8	5.0	
4	10/20/62	119.2	1450			67,000	66,500	60,200	54,000	84,500	118,000	2240	0.9	6.2	
5	10/20/62	128.2	1435			74,000	86,600	69,000	59,400	N.R.	N.R.	3210	N.R.	N.R.	
6	10/20/62	135.6	1445			71,000	78,900	70,000	61,800	107,100	135,000	3360	1.1	4.1	
7	10/21/62	78.4	1310	135,000	40	34,100	35,100	21,700	25,900	43,000	51,500	955	0.4	12.5	
8	10/21/62	100.1	1400			50,700	52,800	36,900	42,400	68,800	75,900	2040	0.6	10.3	
9	10/21/62	116.2	1455			63,000	81,500	45,300	51,400	83,000	102,700	2600	0.8	13.0	
10	10/22/62	130.2	1465			74,000	93,500	64,000	66,000	102,900	132,000	3480	1.0	13.4	
11	10/23/62	85.5	1545	220,000	ON ℄	39,400	45,600	40,100	37,800	52,400	83,900	2200	0.5	3.0	
12	10/24/62	101.1	1560			58,000	57,000	60,100	47,200	70,300	113,900	2350	0.6	4.5	
13	10/24/62	114.7	1590			60,400	74,400	75,500	64,600	91,000	150,900	2950	0.8	5.9	
14	10/24/62	123.0	1625			70,500	68,000	83,800	70,400	102,300	162,000	3400	0.9	4.6	
15	10/25/62	129.8	1640			73,600	74,300	90,800	81,300	107,800	189,000	3150	0.9	4.1	
16	10/26/62	78.5	1620	220,000	20	32,600	38,300	33,500	31,400	43,000	68,400	1560	0.4	9.5	
17	10/26/62	104.2	1630		"	55,300	59,500	61,200	54,800	73,400	122,800	2730	0.6	8.6	
18	10/26/62	121.0	1705		"	65,800	81,800	75,200	66,100	101,000	152,900	3080	0.8	8.6	
19	10/27/62	79.5	1640		40	40,100	36,700	35,400	36,700	56,400	68,900	1810	0.4	13.0	
20	10/27/62	102.4	1675		"	54,600	64,000	53,600	63,000	70,200	102,800	2630	0.5	14.6	
21	10/27/62	127.4	1720		"	72,400	94,800	79,800	80,000	102,800	167,900	3805	0.9	12.4	
22	10/28/62	94.0	1660	220,000	60	51,700	45,200	50,900	39,200	81,100	111,100	2260	0.5	19.7	
23	10/28/62	106.8	1660			73,500	64,600	69,400	52,400	82,600	138,500	2910	0.6	13.6	
24	10/28/62	115.4	1655			82,600	69,400	74,200	67,900	93,400	148,300	3300	0.7	13.6	
25	10/28/62	126.0	1675			92,800	78,300	88,900	71,400	111,000	183,800	3440	0.9	17.6	
26	10/29/62	116.0	1690	220,000	40	65,500	77,700	66,400	67,500	95,500	165,800	3240	0.8	13.0	
27	10/29/62	123.2	1700	"	20	77,400	68,200	82,500	71,300	114,300	180,500	2950	0.9	9.6	
28	10/30/62	96.4	670	175,000	10	47,600	40,100	N.R.	N.R.	47,700	N.R.	N.R.	0.9	7.7	LANDING ARR.
27	11/8/62	133.8	N.R.	"	ON ℄	N.R.	77,500	N.R.	71,100	N.R.	N.R.	2240	N.R.	N.R.	DEMON.
30	11/9/62	116.1	N.R.	"	" "	N.R.	62,700	N.R.	50,000	N.R.	N.R.	2260	N.R.	N.R.	"

Figure 26 Model 3500 Arresting Gear Data, Boeing 720-027 Arrestment Data

RUN NO.	DIST FROM ℄	ENG'G VEL.	MAX HOOK LOAD	HOOK ANG AT MAX. LD.	MAX HOOK ANGLE	HOOK LD. AT MAX. ANG
	FEET	KNOTS	LBS.	DEG.	DEG.	LBS.
1	ON ℄	80.8	66,200	1.4	6.1	41,000
2		120.8	N.R.	N.R.	3.5	N.R.
3		106.5	96,300	4.3	5.0	56,200
4		119.2	118,000	0.9	6.2	68,500
5		128.2	N.R.	N.R.	N.R.	N.R.
6		135.6	135,000	0.5	4.1	71,200
7	40	78.4	51,500	1.4	12.5	10,300
8		100.1	75,900	4.0	10.3	50,600
9		116.2	102,700	1.8	13.0	56,600
10		130.2	132,000	0.5	13.4	40,200
11	ON ℄	85.5	83,900	0.5	3.0	20,800
12		101.1	113,900	1.0	4.5	62,900
13		114.7	150,900	0.5	5.9	75,700
14		123.0	162,000	0.5	4.6	92,500
15		129.8	189,800	0.9	4.1	91,400
16	20	78.5	68,400	1.4	9.5	10,100
17		104.2	122,800	0.0	8.6	21,500
18		121.0	152,900	1.2	8.6	72,000
19	40	79.5	68,900	1.8	13.0	10,300
20		102.4	102,800	3.6	14.6	41,400
21		127.4	167,900	2.0	12.4	67,600
22	60	94.0	111,100	0.9	19.7	14,300
23		106.8	138,500	0.5	13.6	12,700
24		115.4	148,300	0.0	13.6	85,400
25		126.0	183,800	0.0	17.6	14,500
26	40	116.0	165,800	0.0	13.0	67,000
27	20	123.2	180,500	1.7	9.6	66,100
28	10	96.4	47,700	1.6	7.7	31,800

Figure 27 Boeing 720 Hook Position Data

TEST REPORT

SERIAL NO. REV. DATE:

SUBJECT: BOEING 720 HOOK SHANK SER. NO. 3 (See Test Requisition for Complete Data)	Dwg. No.	Test Date: JAN. 2, 1963
	Mat'l: 4340	S.O. 1485
	Customer:	Location: M & P LAB.

	SPECIMEN NO.	AREA (IN.²)	Y/S .02 OFFSET (P.S.I.)	Y/S .2 OFFSET (P.S.I.)	U/S (P.S.I.)	ELONG. IN 2 IN. (%)	REDUCT. OF AREA (%)	HARDNESS "Rc"	
	1TN	.0747	182,000	193,000	204,000	6.5	41	44	
	2TN	.0756	185,000	192,000	204,000	8.5	44	44	
	3TN	.0775	183,000	191,000	203,500	8.5	44	44	
	4TY	.0782	189,000	194,500	201,000	8.5	44	44	
	5TY	.0797	186,000	194,500	204,000	8.0	44	44	
	6TY	.0785	194,500	196,500	205,000	8.5	46	44	
	1LN	.218	136,500	183,000	203,000	11.5	42	44	
	2LN	.219	136,000	180,500	200,500	12.5	42	44	
	3LN	.218	137,000	183,500	203,000	12.5	45	44	
	4LY	.216	157,500	190,000	201,500	12.5	46	44	
	5LY	.218	160,500	191,500	202,500	12.0	43	44	
	6LY	.218	160,500	192,500	204,000	12.0	46	44	

Operator: E.F.S.	Witness:	Approval:	DISTRIBUTION:
NEGATIVE NOS.			Prod. Engr. Tech. Ed. Test Dir. Stress Metall. Engr. Instr. Engr. Tech. Clerk Test. Engr.

Figure 28 Data from Tensile Specimens Taken from Boeing 720 Spring Shank Used During Aircraft Tests

RUN No. →		42	43	44	45	46	47	53	54	55	
OBSTACLE LOCATION BY RUNWAY STATION	OBSTACLE TYPE + CONFIGURATION	HORIZONTAL HOOK TRAVEL FROM STRUCK OBSTACLE TO GROUND LINE (FEET) / HORIZONTAL HOOK VELOCITY AT OBSTACLE (KNOTS)									REMARKS
1400	6 IN. LGT. BASE	NOT USED	NOT USED	52/92	—	59/N.R.	77/N.R.	—	62/110	—	
1425				—	52/N.R.	—	—	—	—	65/115	
1450				—	—	—	—	42/110	—	—	
1475				60/95	—	—	—	—	20/112	—	
2000	8 IN. LGT BASE			58/105	60/N.R.	22/N.R.	45/N.R.	—	21/120	71/130	
2025				—	—	69/N.R.	—	—	65/120	—	
2050				—	—	—	140/N.R.	—	—	—	
2075				—	—	—	—	—	—	70/130	
1600	3 FT. x 1½ IN. RAMP	40/91	54/95	54/96	46/N.R.	23/N.R.	—	31/110	20/112	41/120	HOOK ON RAMP CREST, RUNS 44, 53-55; ½ IN. OFF CREST, RUN 45
2200	2 FT. x 1½ IN. RAMP	50/96	60/105	68/108	—	NOT USED	NOT USED	NOT USED	NOT USED	NOT USED	HOOK ½ to 1 IN. OFF CREST RUN 44
2200	6 FT. x 1½ IN. RAMP	NOT USED	NOT USED	NOT USED	NOT USED	41/N.R.	63/N.R.	—	NOT USED	NOT USED	HOOK ON RAMP CREST, RUN 47; ¾ IN. OFF CREST, RUN 46
2200	10 FT x 1½ IN. RAMP	NOT USED	NOT USED	NOT USED	NOT USED	NOT USED	NOT USED	NOT USED	27/122	58/135	HOOK ON RAMP CREST, RUN 54; 1¼ IN. OFF CREST, RUN 55

NOTE: LINED BLANK SPACE INDICATES THAT HOOK MISSED OBSTACLE.

Figure 29 Hook Bounce Data

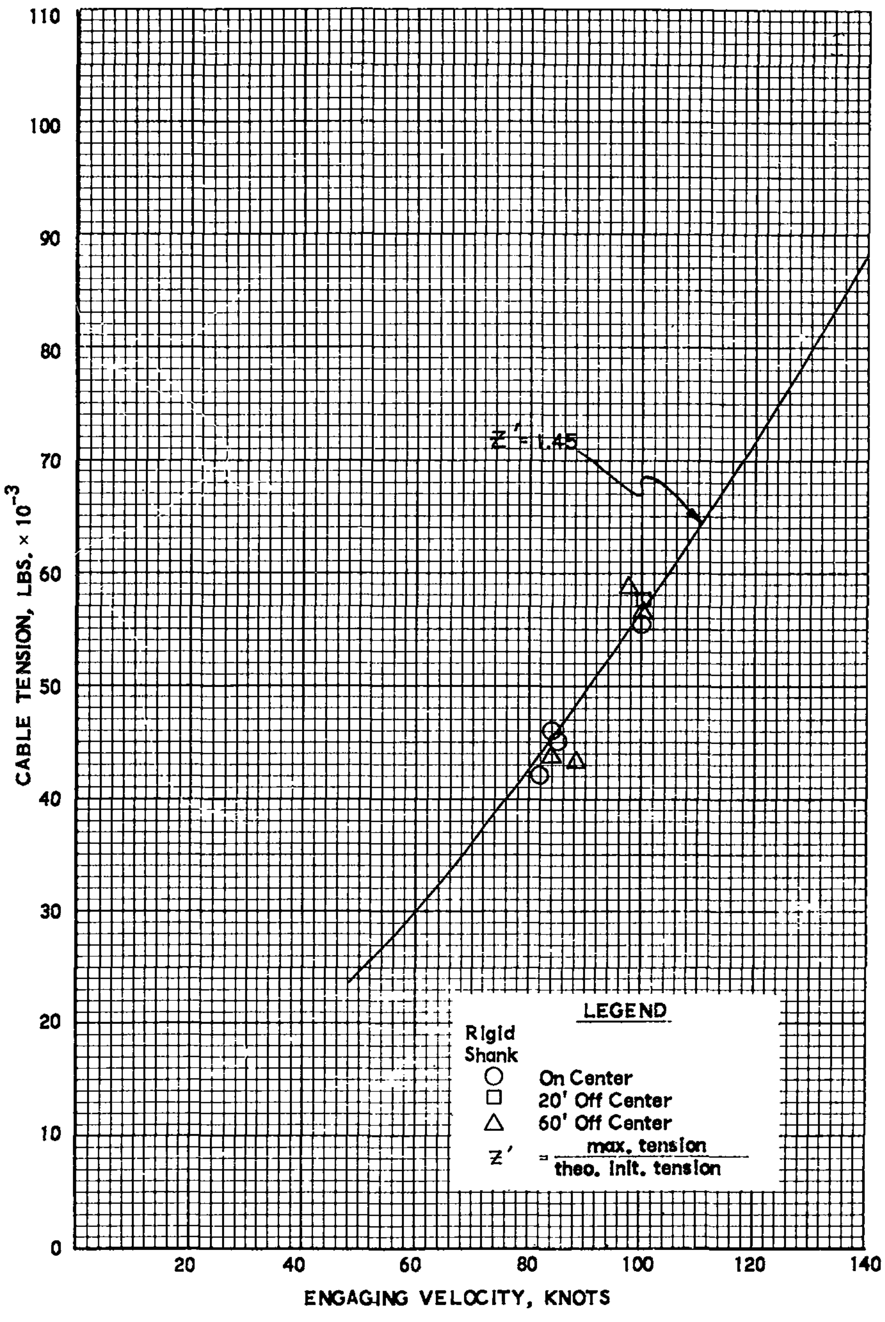


Figure 30 Maximum Dynamic Cable Tension vs. Engaging Velocity, 50,000-pound Dead Load

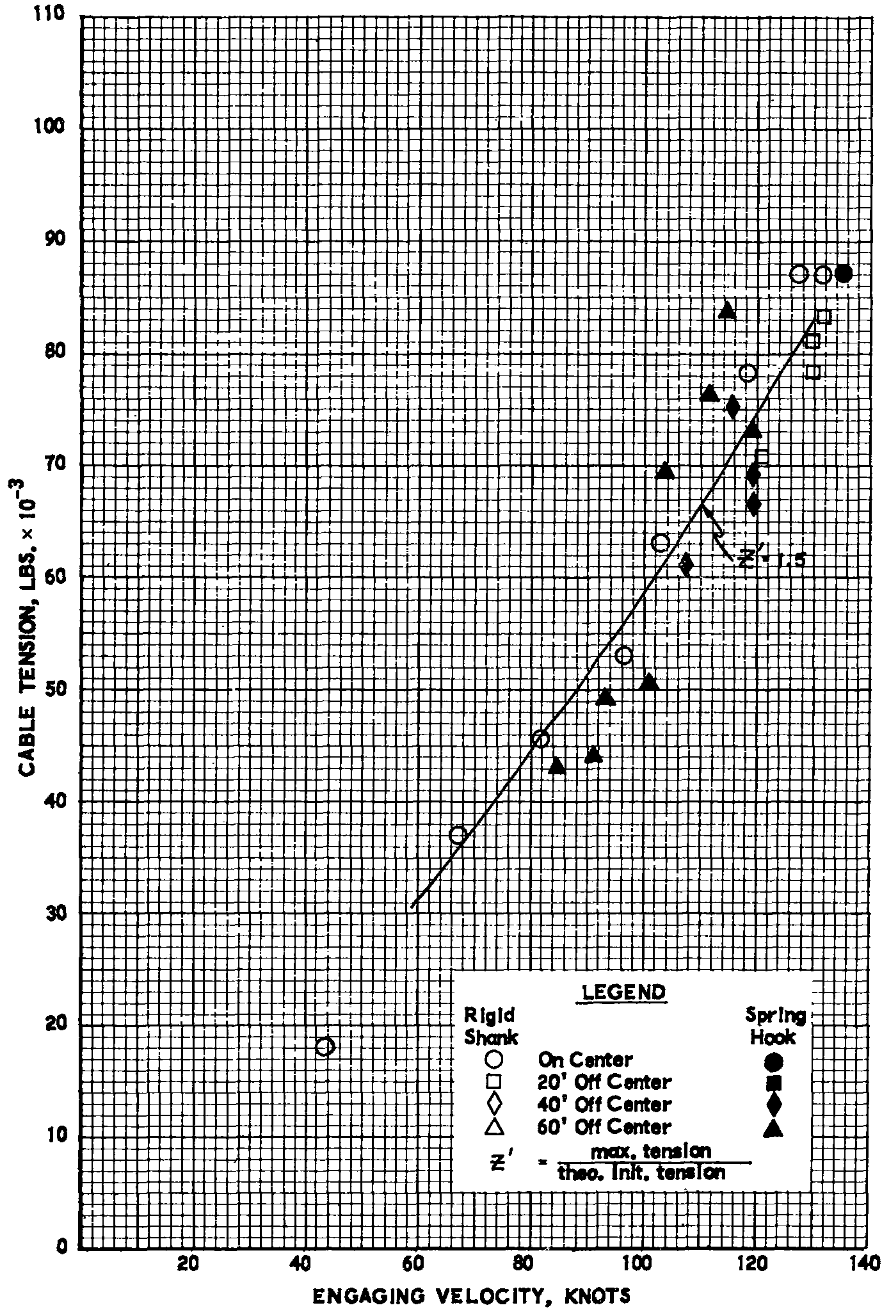


Figure 31 Maximum Dynamic Cable Tension vs. Engaging Velocity, 200,000-pound Dead Load

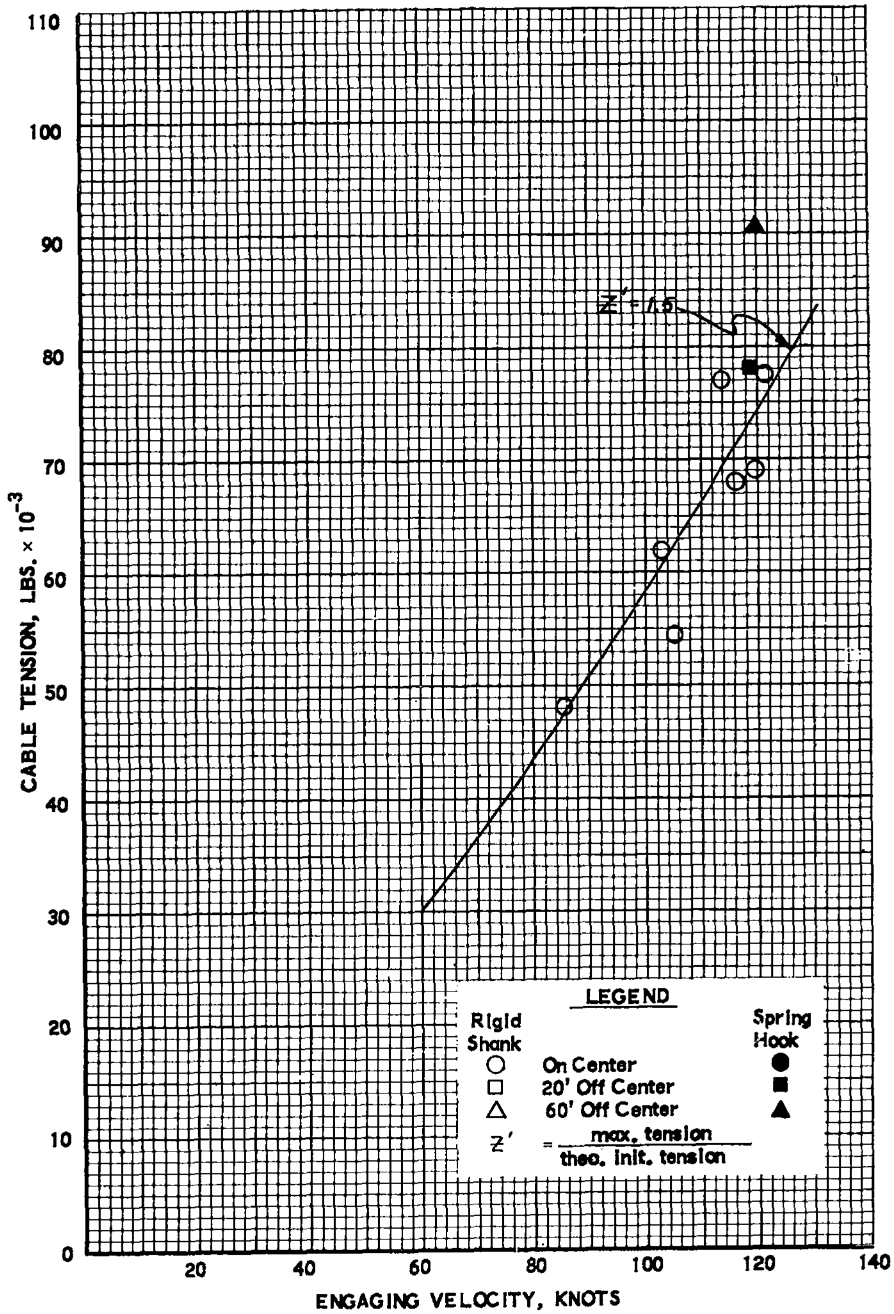


Figure 32 Maximum Dynamic Cable Tension vs. Engaging Velocity, 300,000-pound Dead Load

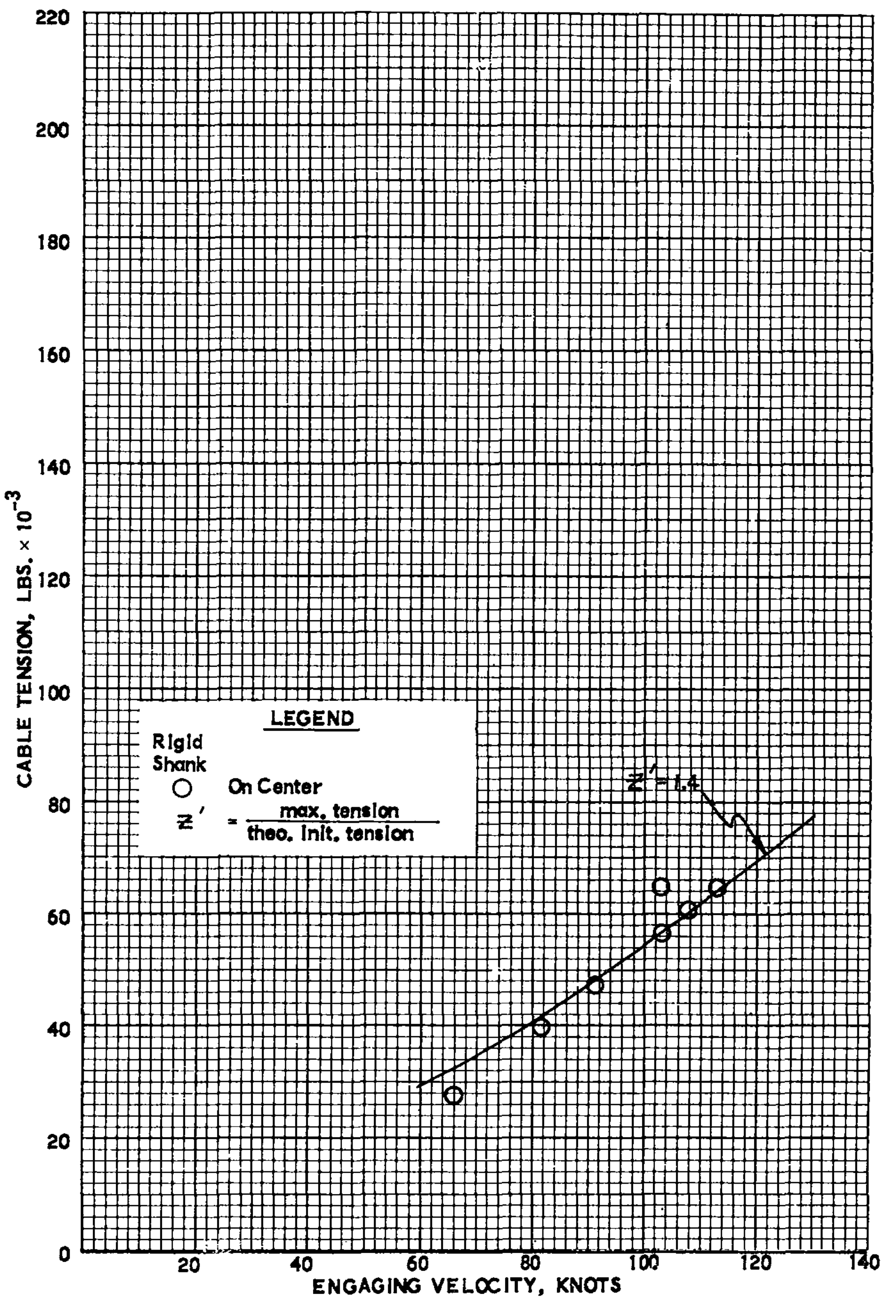


Figure 33 Maximum Dynamic Cable Tension vs Engaging Velocity, 350,000-pound Dead Load

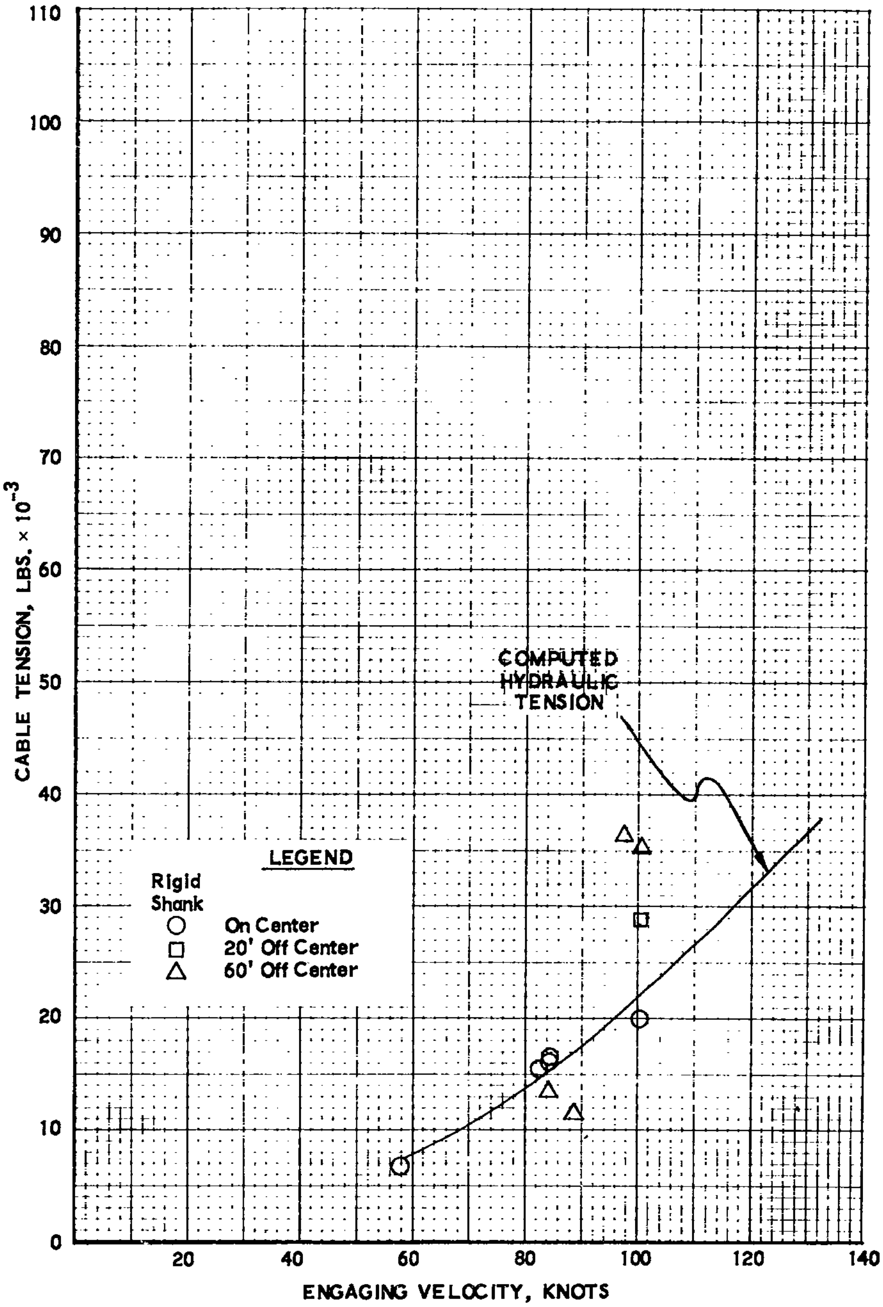


Figure 34 Maximum Hydraulic Cable Tension vs. Engaging Velocity, 50,000-pound Dead Load

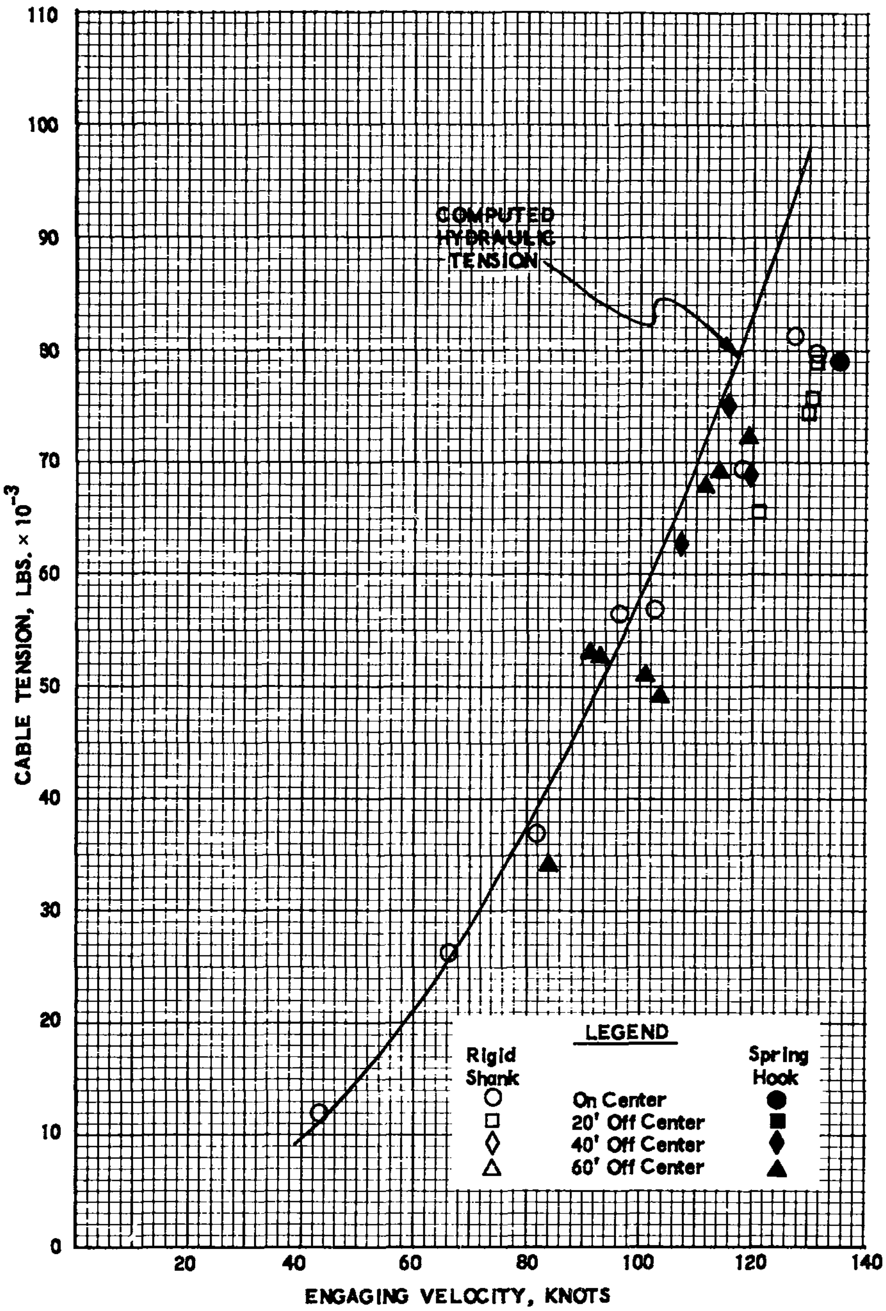


Figure 35 Maximum Hydraulic Cable Tension vs Engaging Velocity, 200,000-pound Dead Load

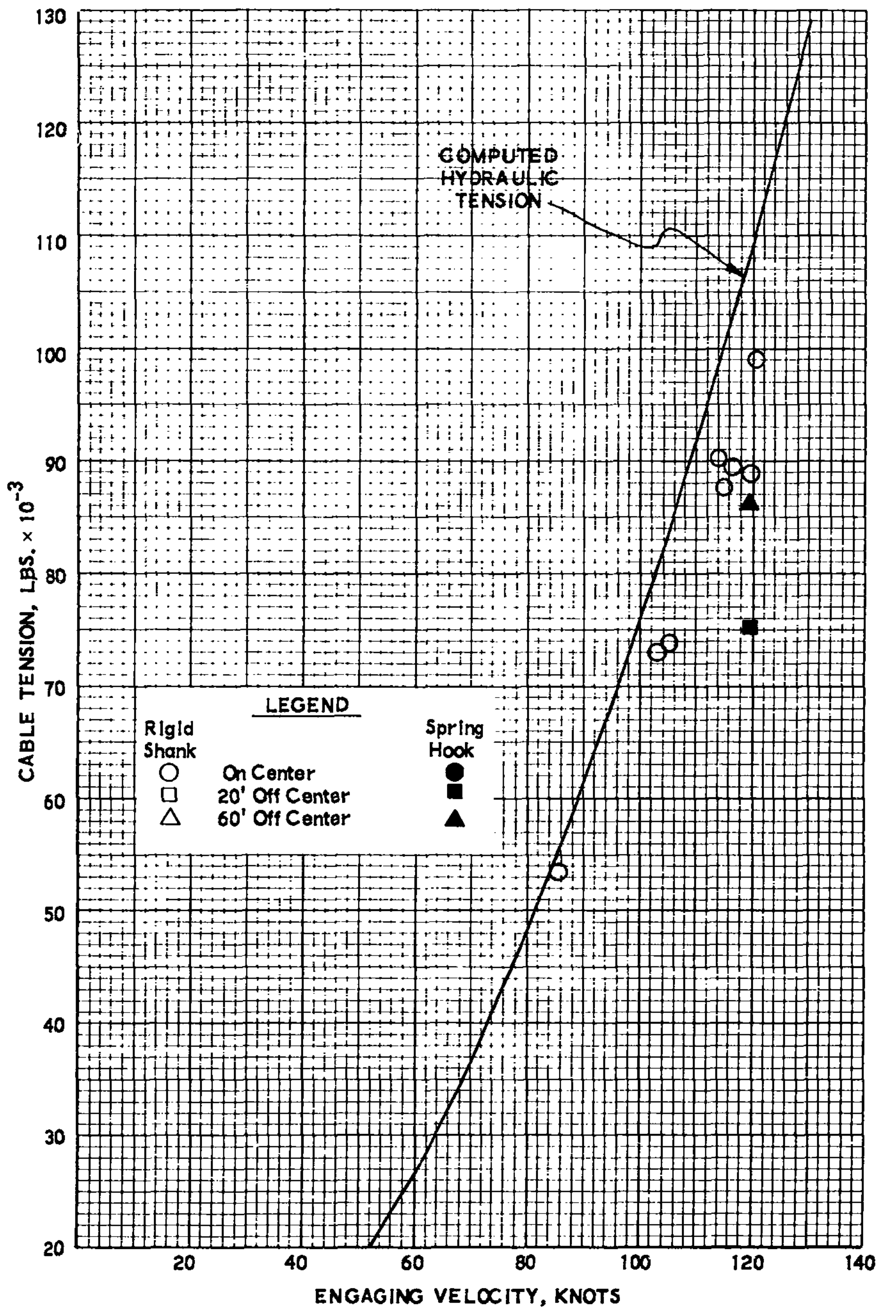


Figure 36 Maximum Hydraulic Cable Tension vs. Engaging Velocity, 300,000-pound Dead Load

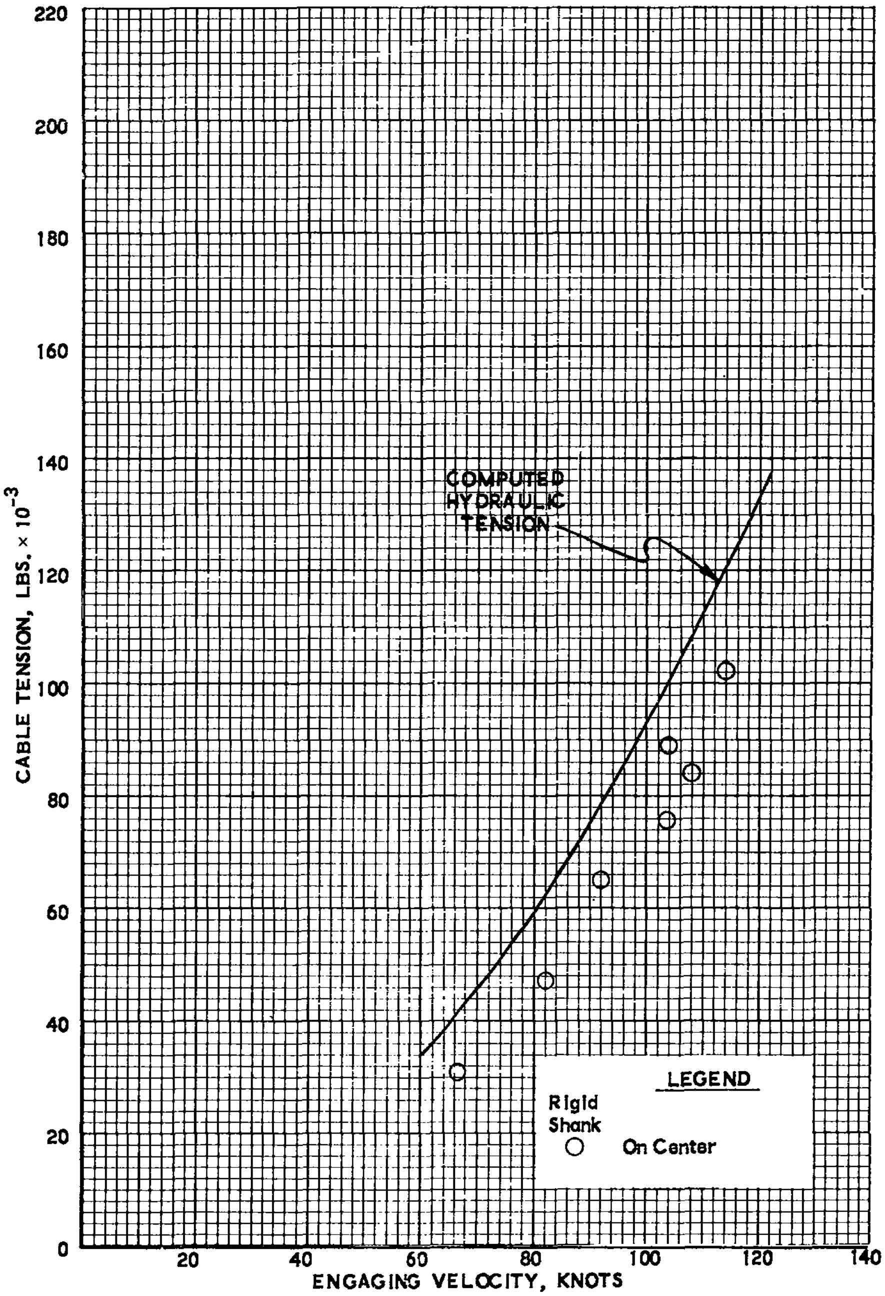


Figure 37 Maximum Hydraulic Cable Tension vs. Engaging Velocity, 350,000-pound Dead Load

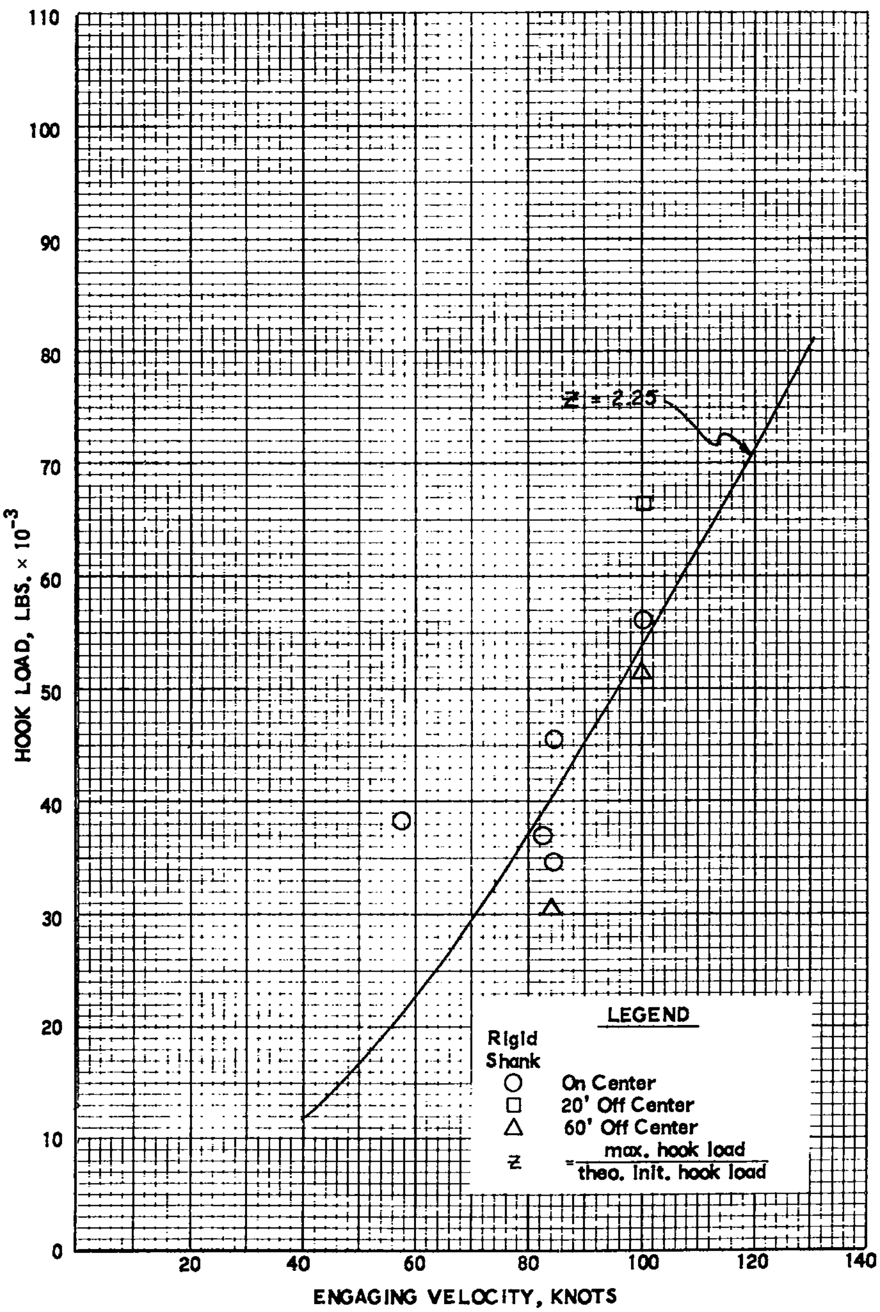


Figure 38 Maximum Dynamic Hook Load vs. Engaging Velocity, 50,000-pound Dead Load

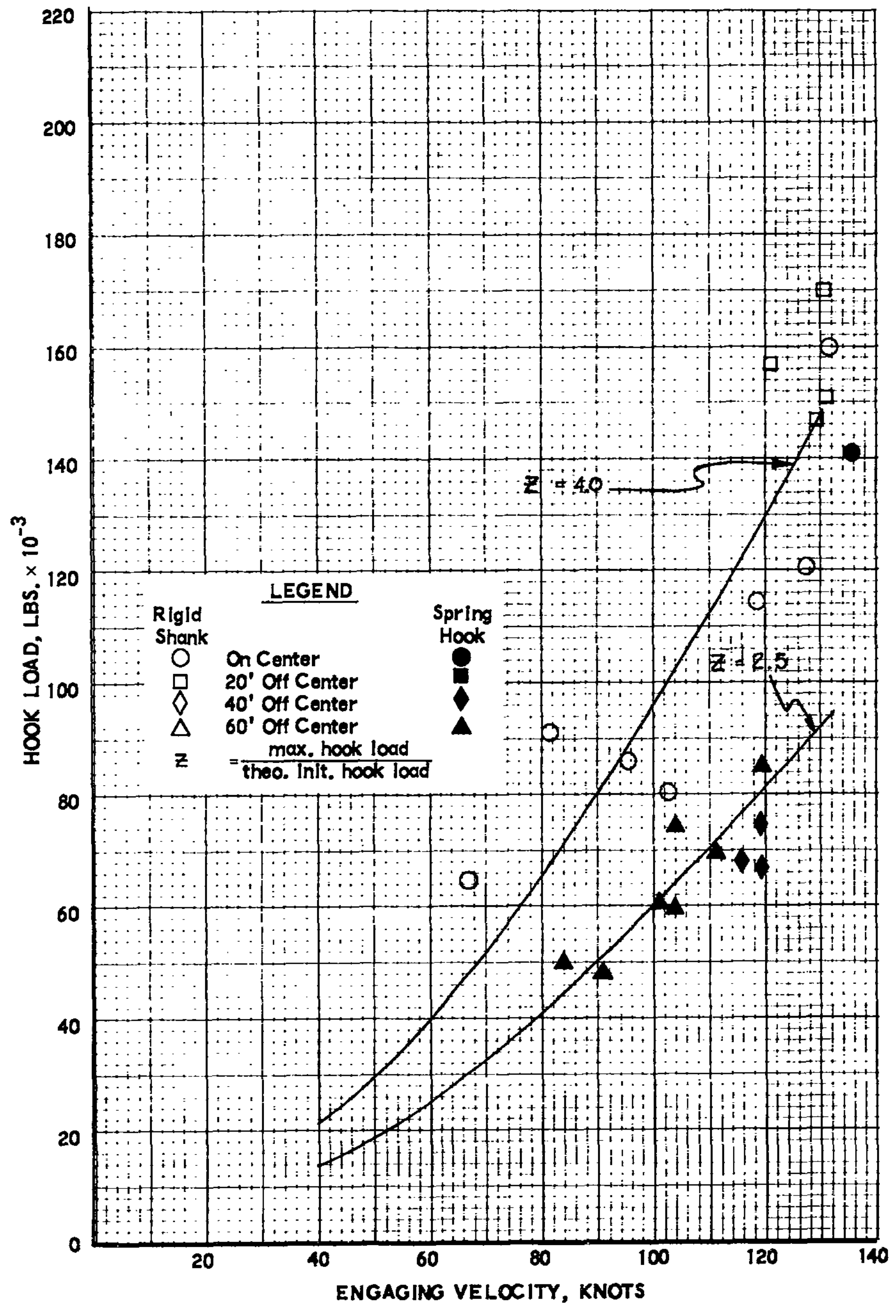


Figure 39 Maximum Dynamic Hook Load vs. Engaging Velocity, 200,000-pound Dead Load

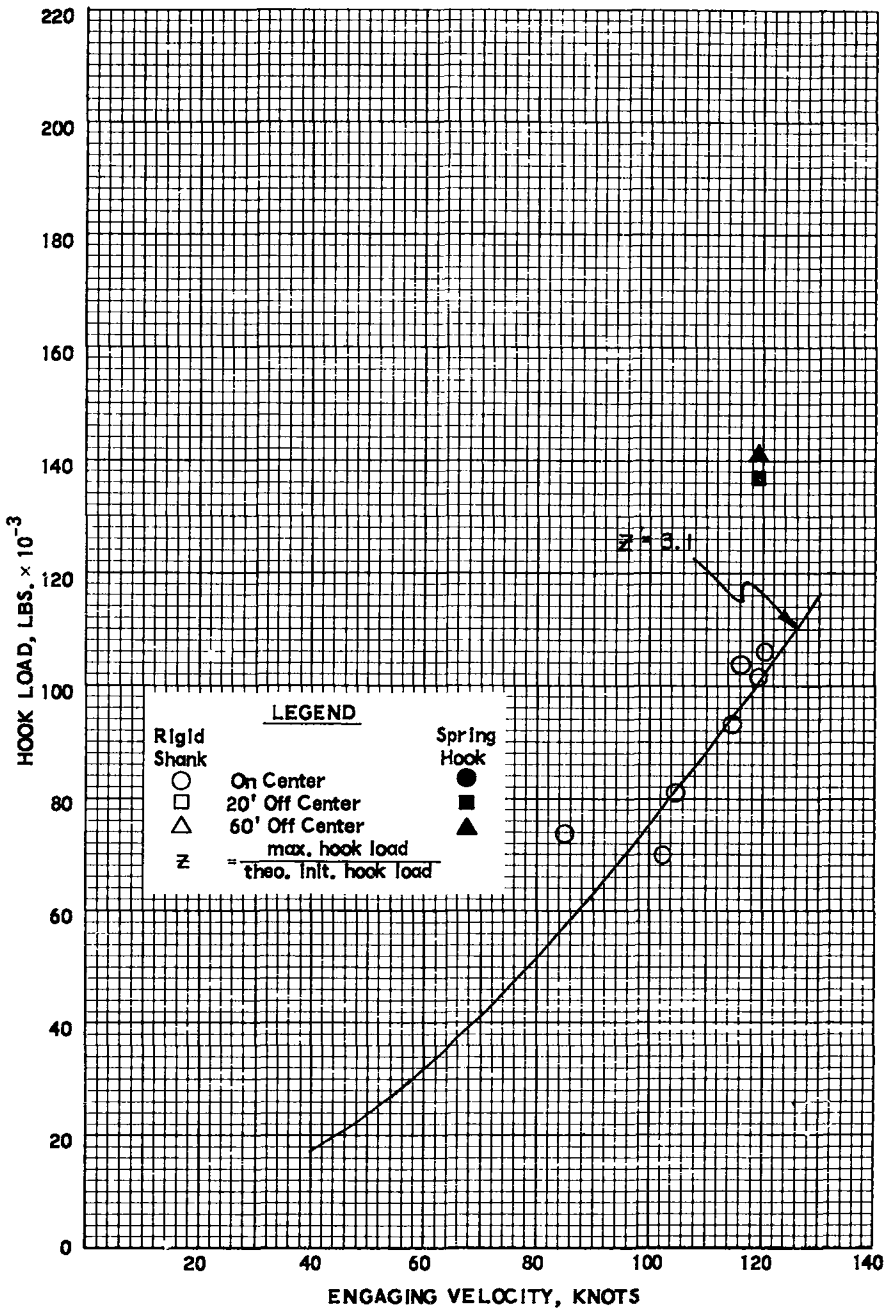


Figure 40 Maximum Dynamic Hook Load vs. Engaging Velocity, 300,000-pound Dead Load

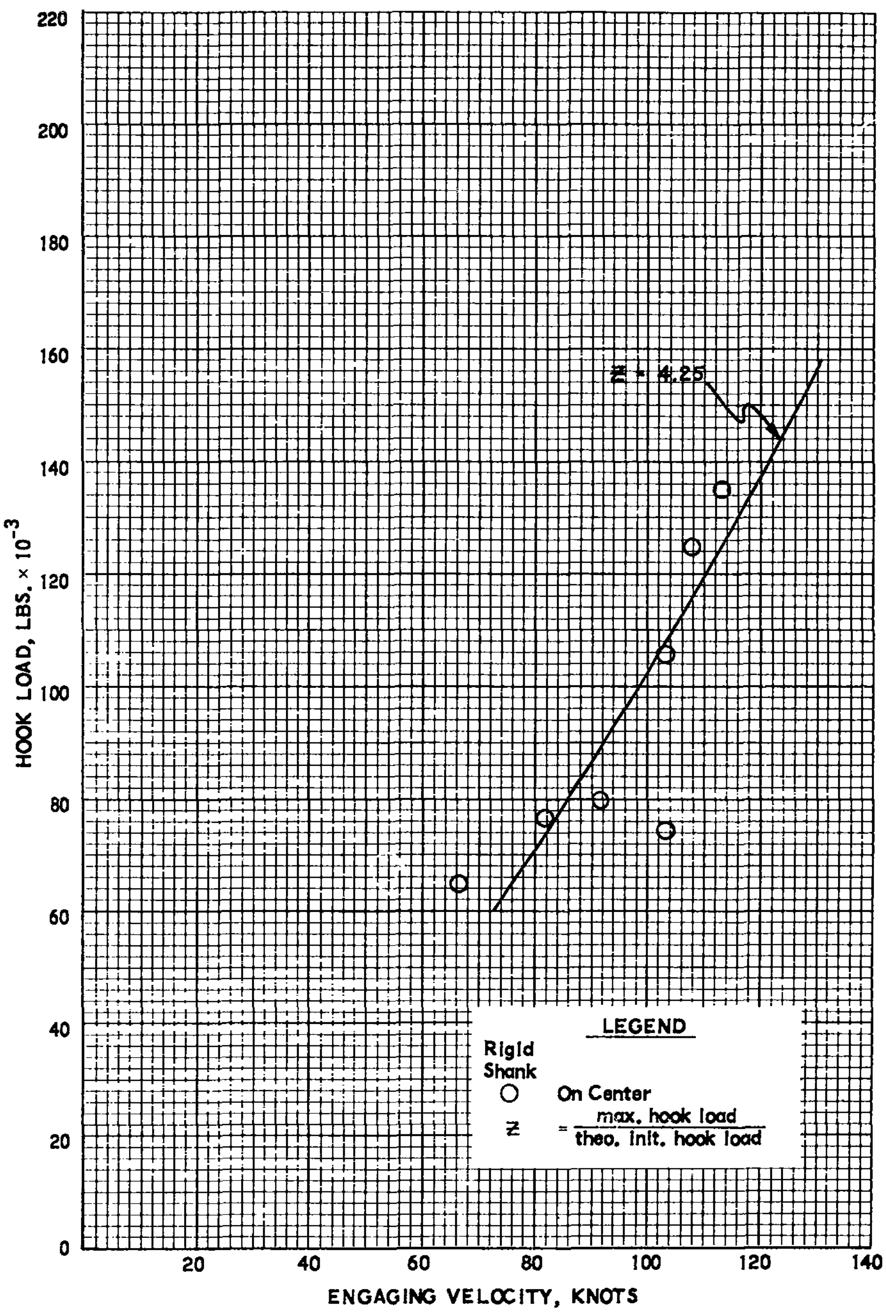


Figure 41 Maximum Dynamic Hook Load vs. Engaging Velocity, 350,000-pound Dead Load

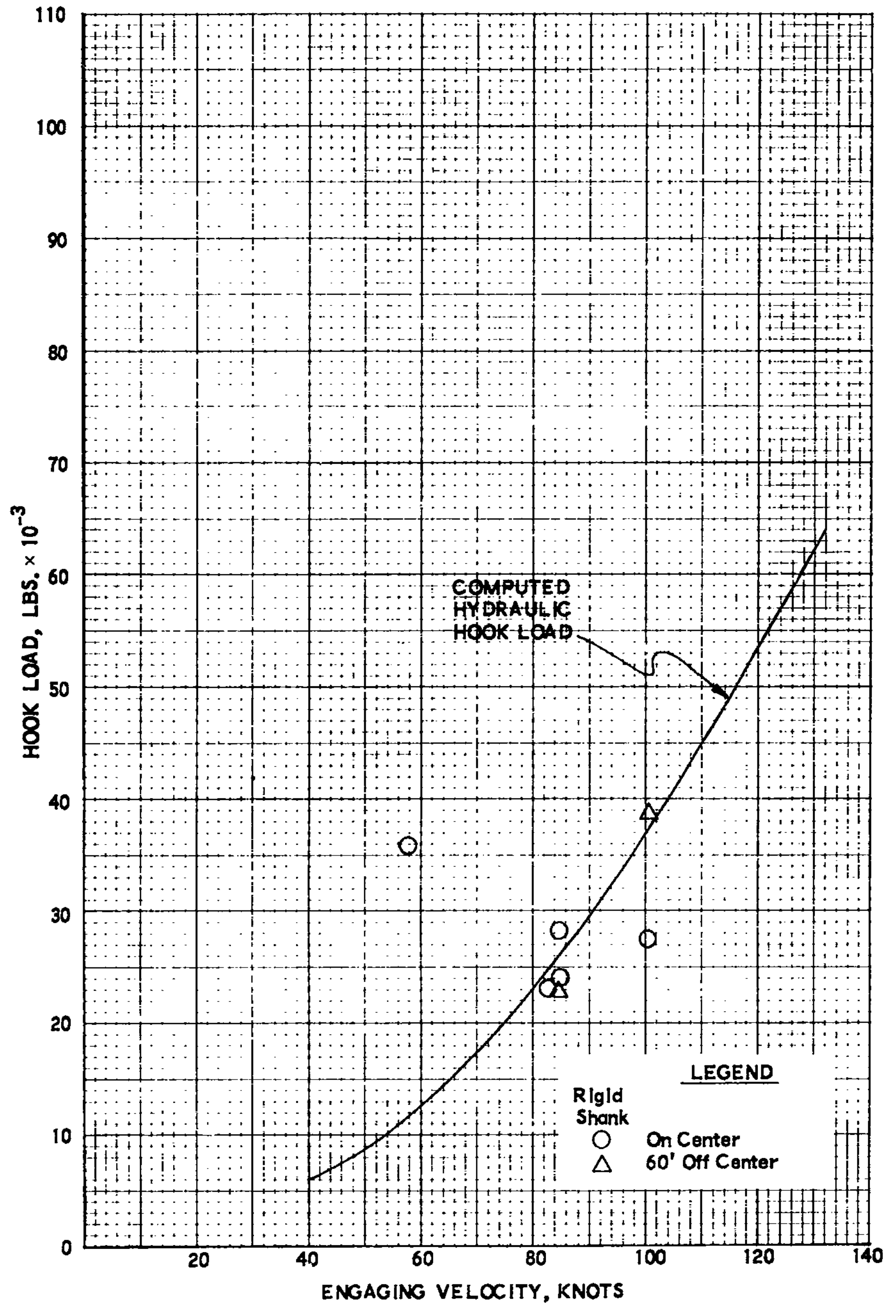


Figure 42 Maximum Hydraulic Hook Load vs. Engaging Velocity, 50,000-pound Dead Load

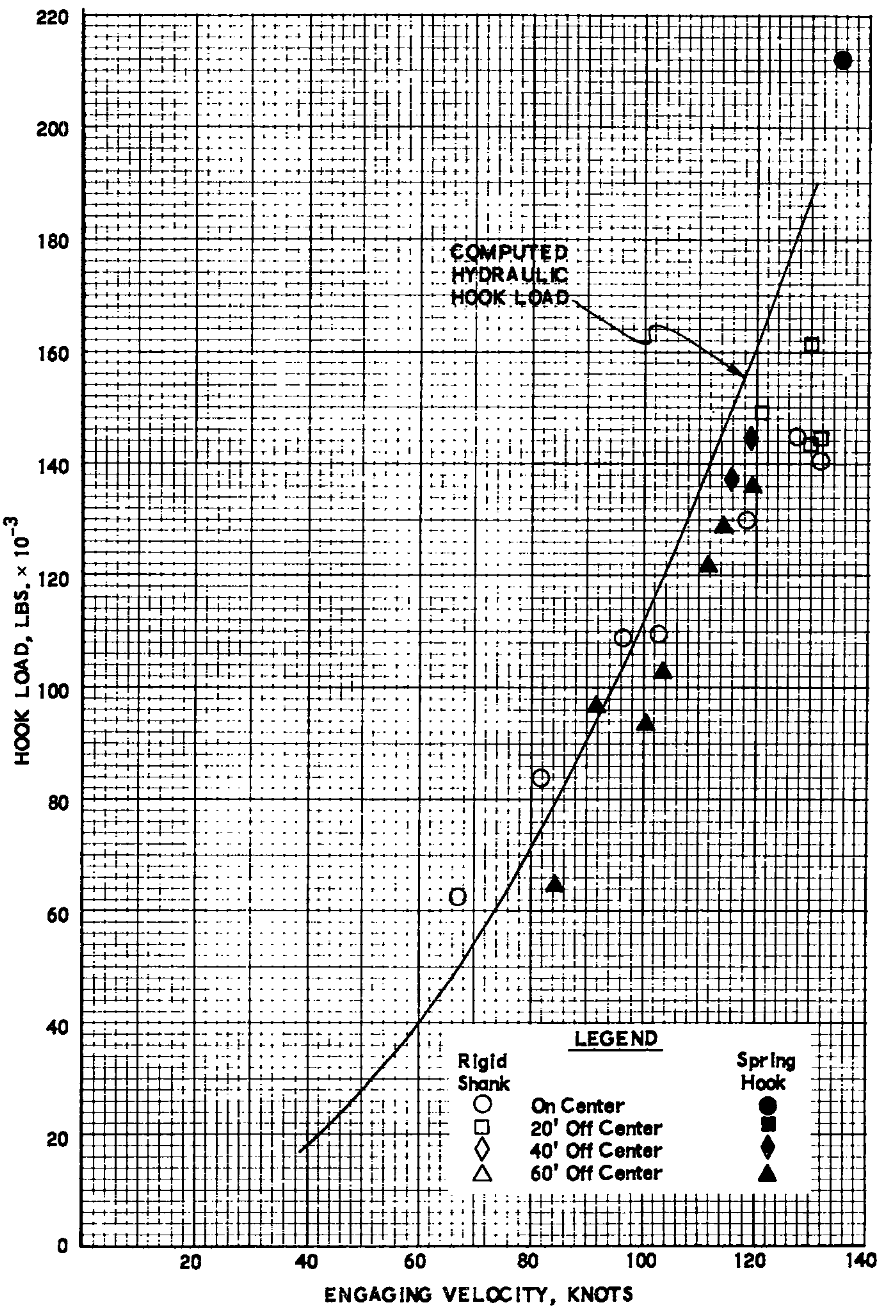


Figure 43 Maximum Hydraulic Hook Load vs Engaging Velocity, 200,000-pound Dead Load

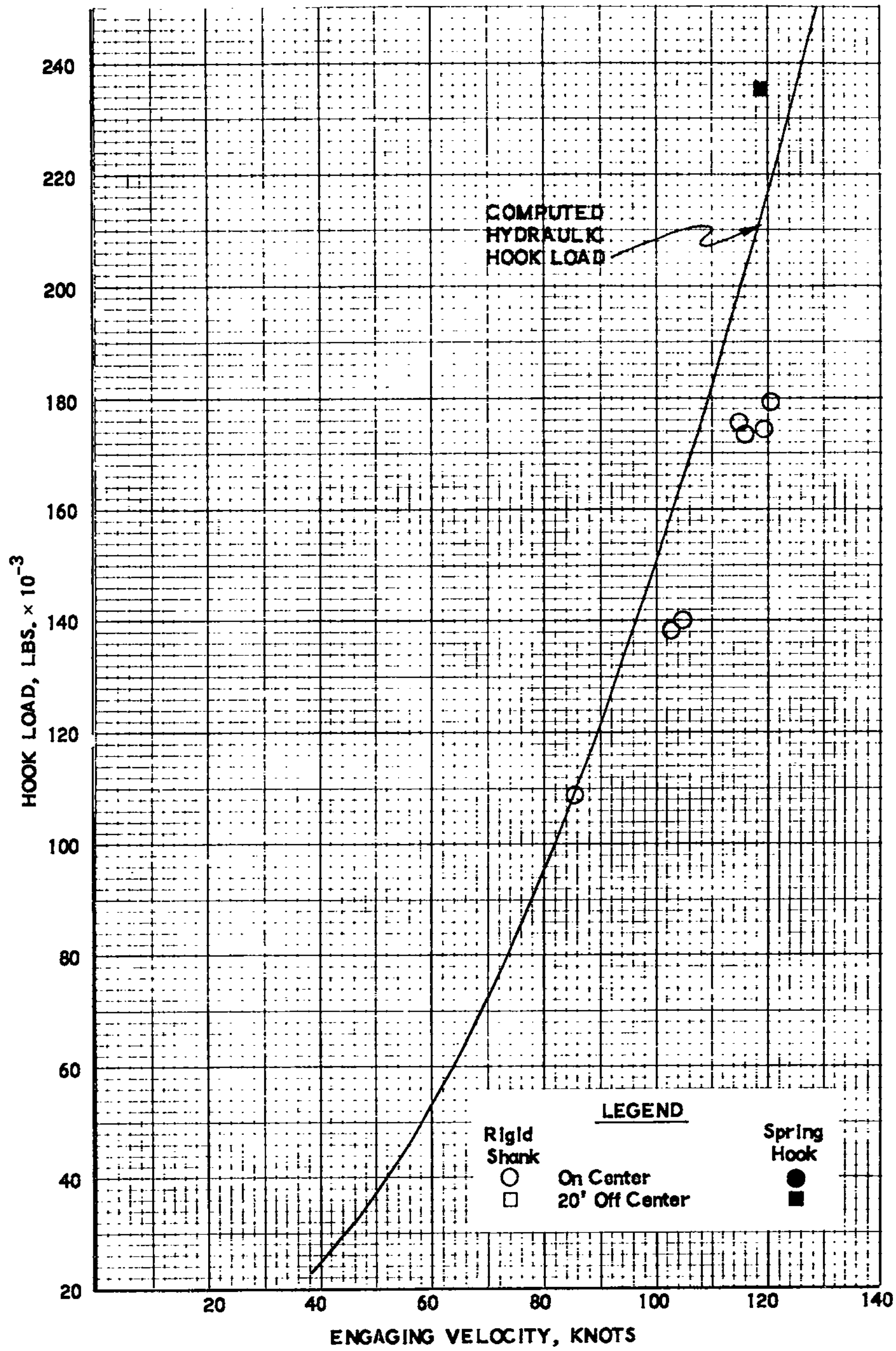
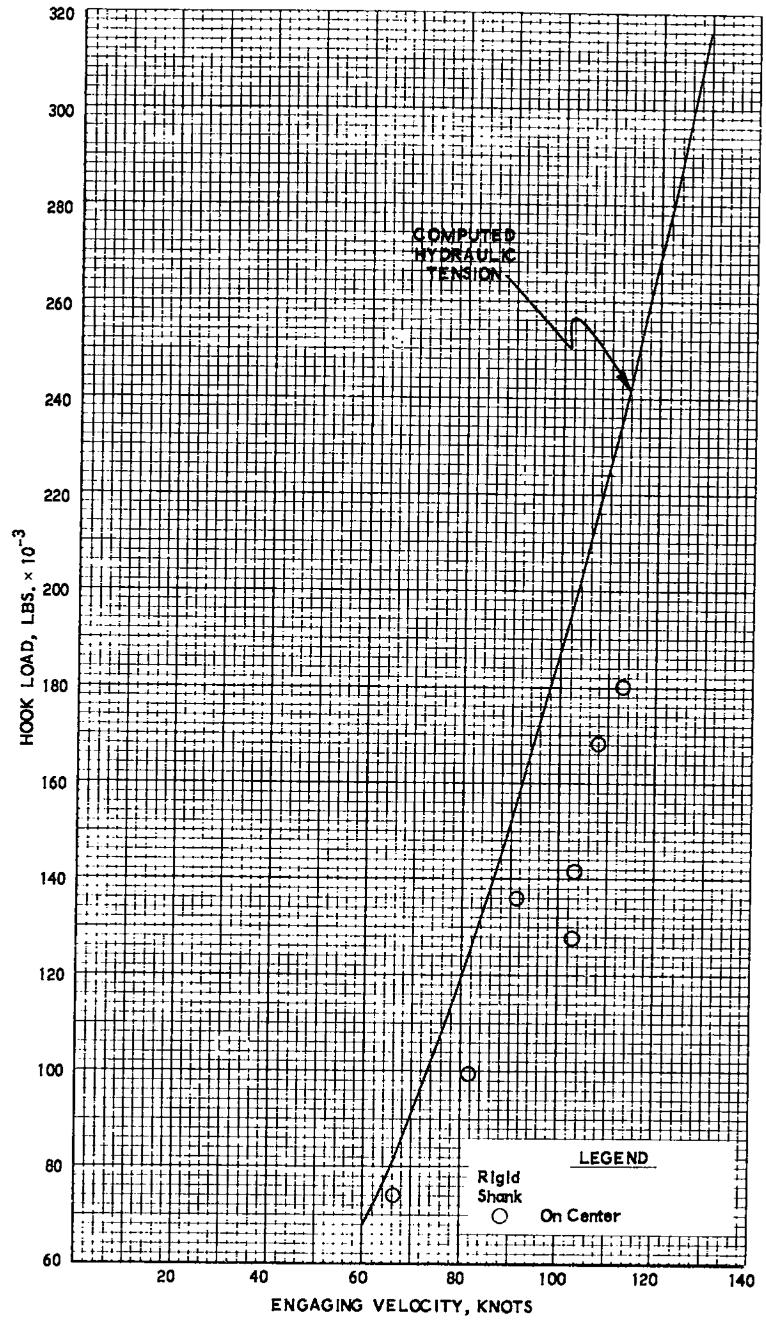


Figure 44 Maximum Hydraulic Hook Load vs. Engaging Velocity, 300,000-pound Dead Load



igure 45 Maximum Hydraulic Hook Load vs. Engaging Velocity, 350,000-pound Dead Load

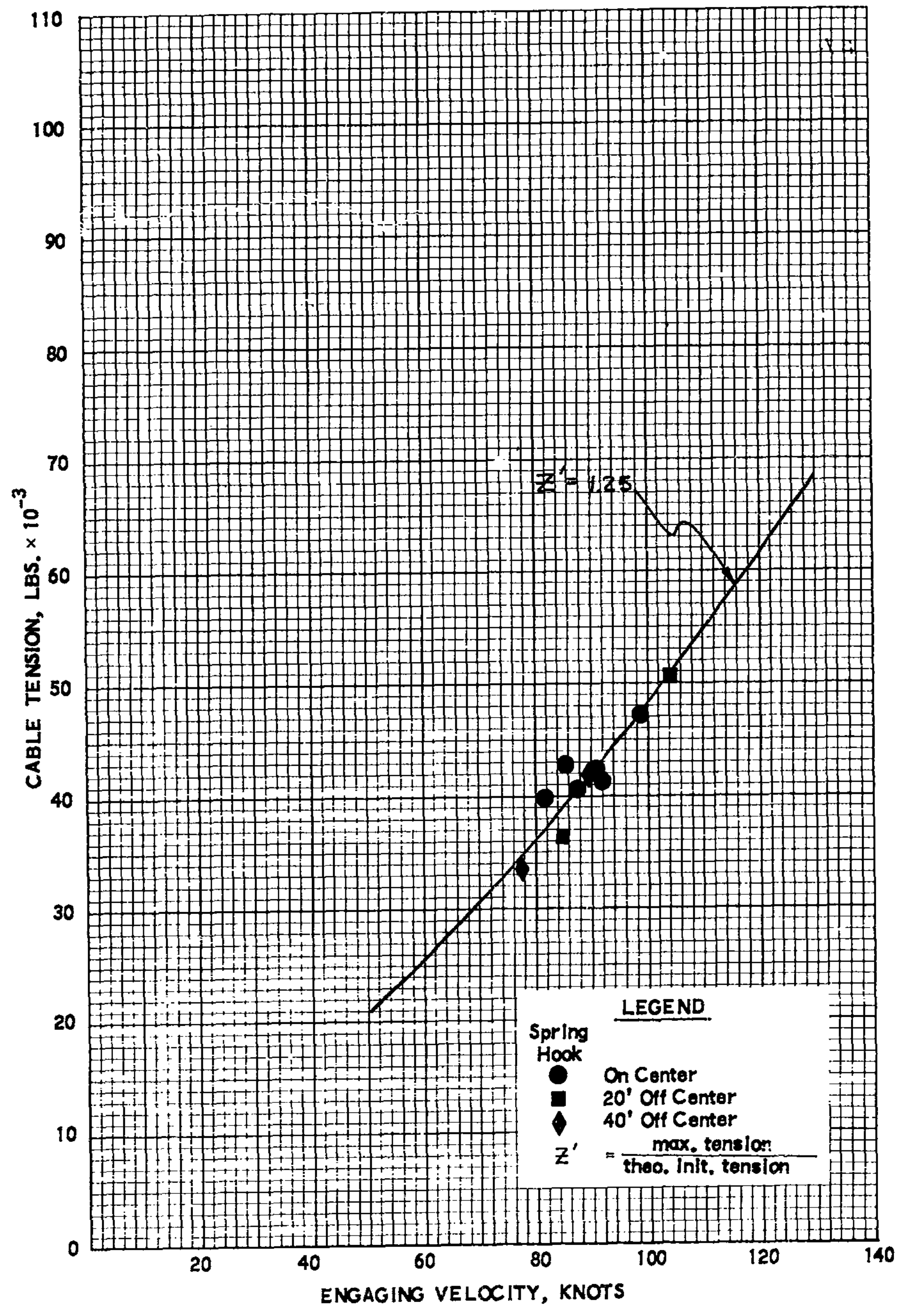


Figure 46 Maximum Dynamic Cable Tension vs. Engaging Velocity, C-131B at 50,000 Pounds

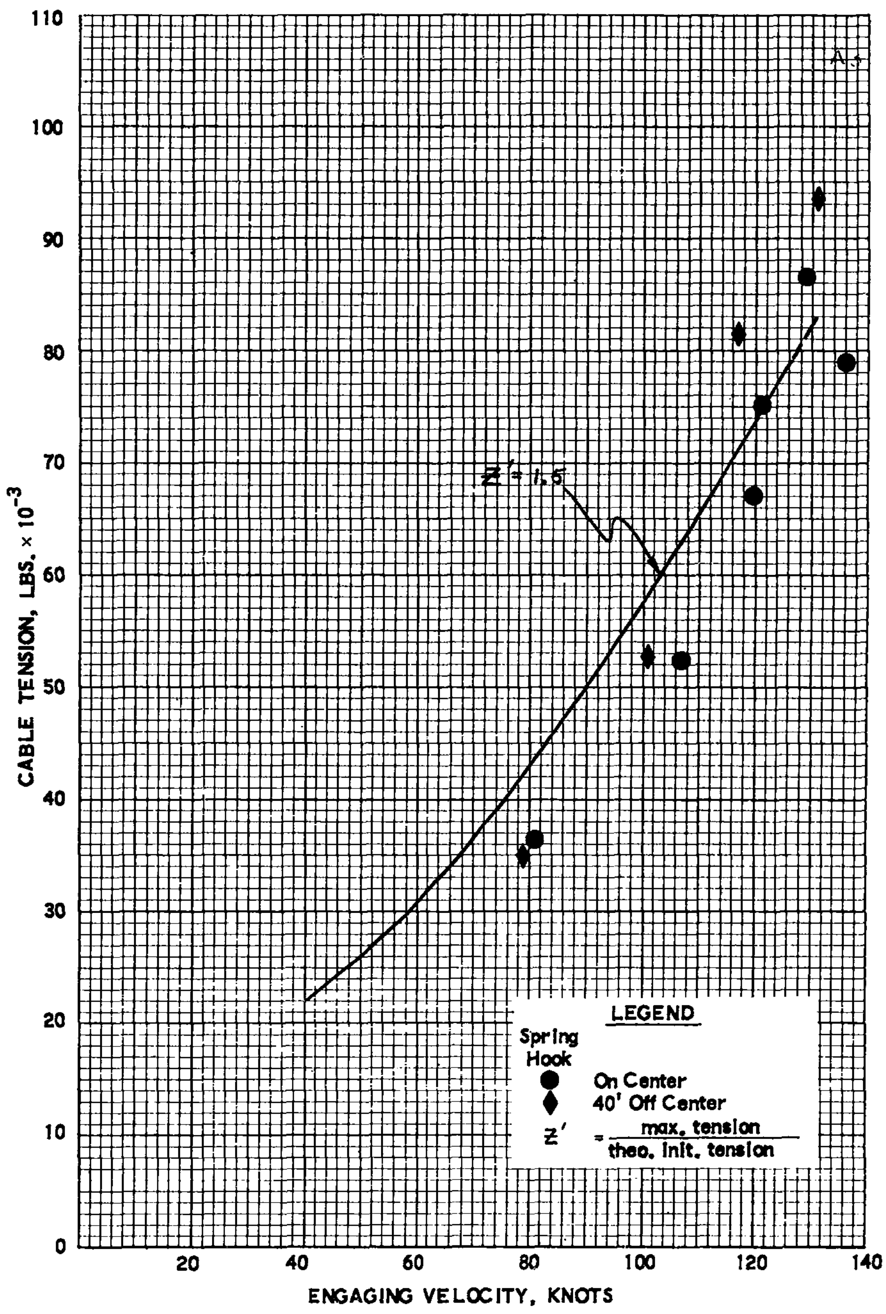


Figure 47 Maximum Dynamic Cable Tension vs. Engaging Velocity, Boeing 720 at 135,000 Pounds

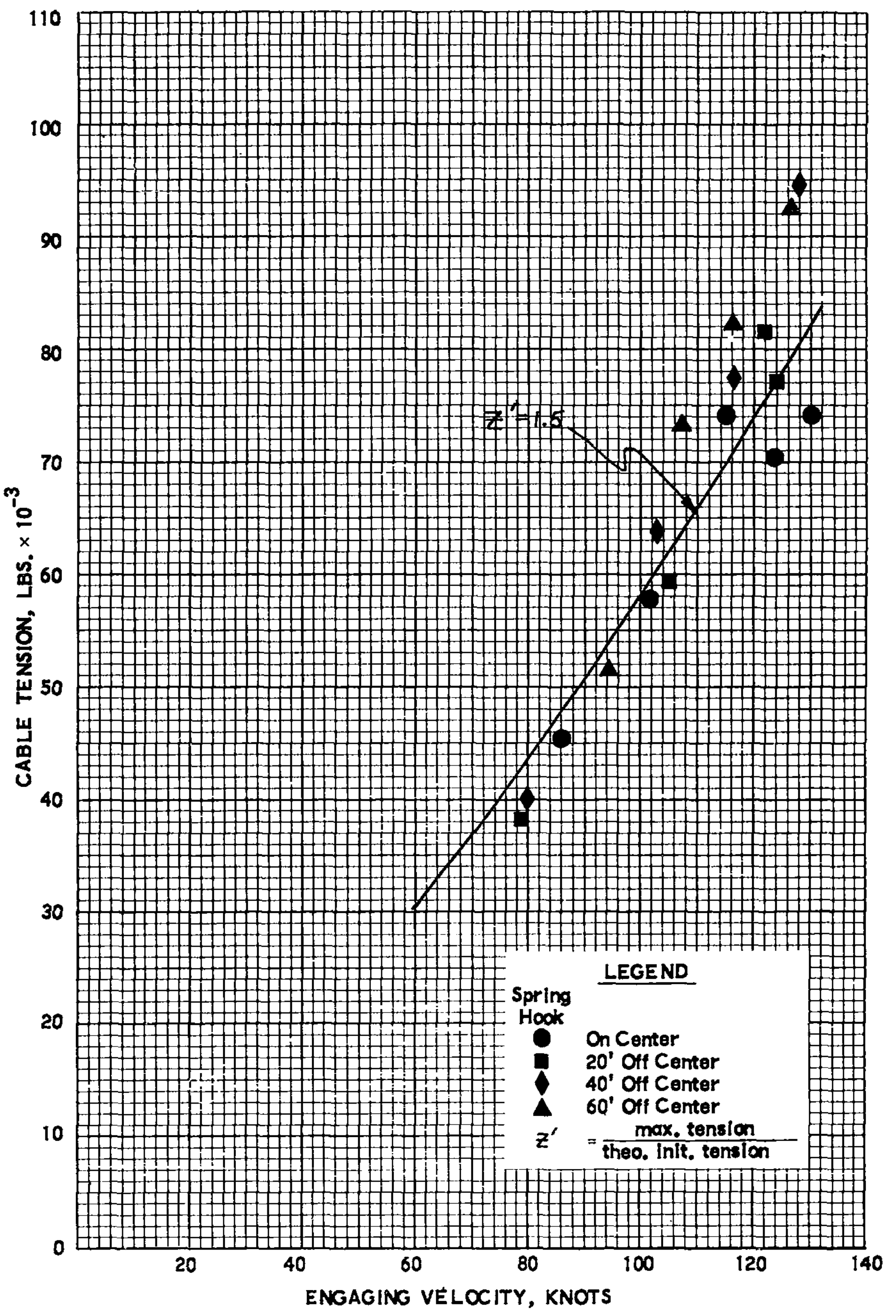


Figure 48 Maximum Dynamic Cable Tension vs. Engaging Velocity, Boeing 720 at 220,000 Pounds

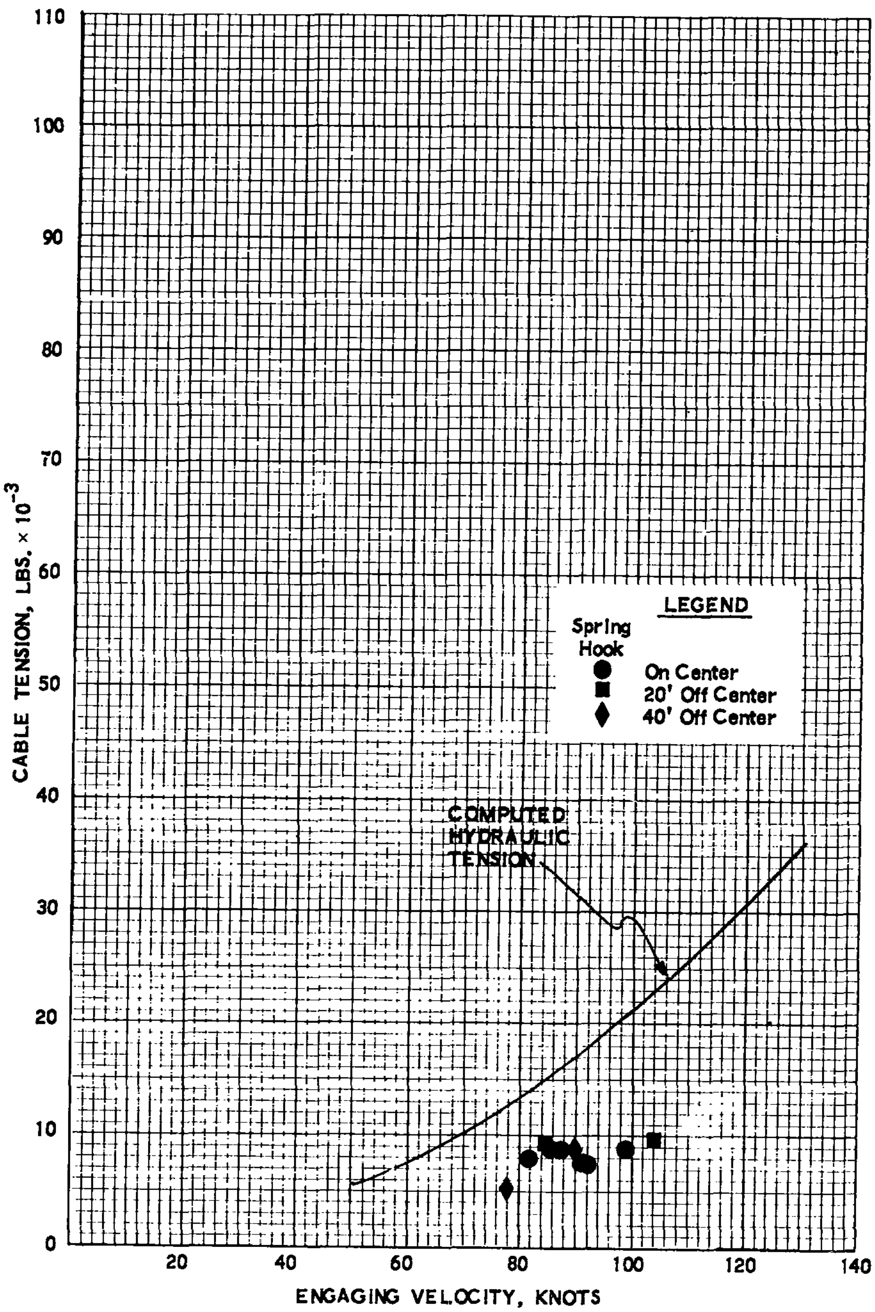


Figure 49 Maximum Hydraulic Cable Tension vs. Engaging Velocity, C-131B at 50,000 Pounds

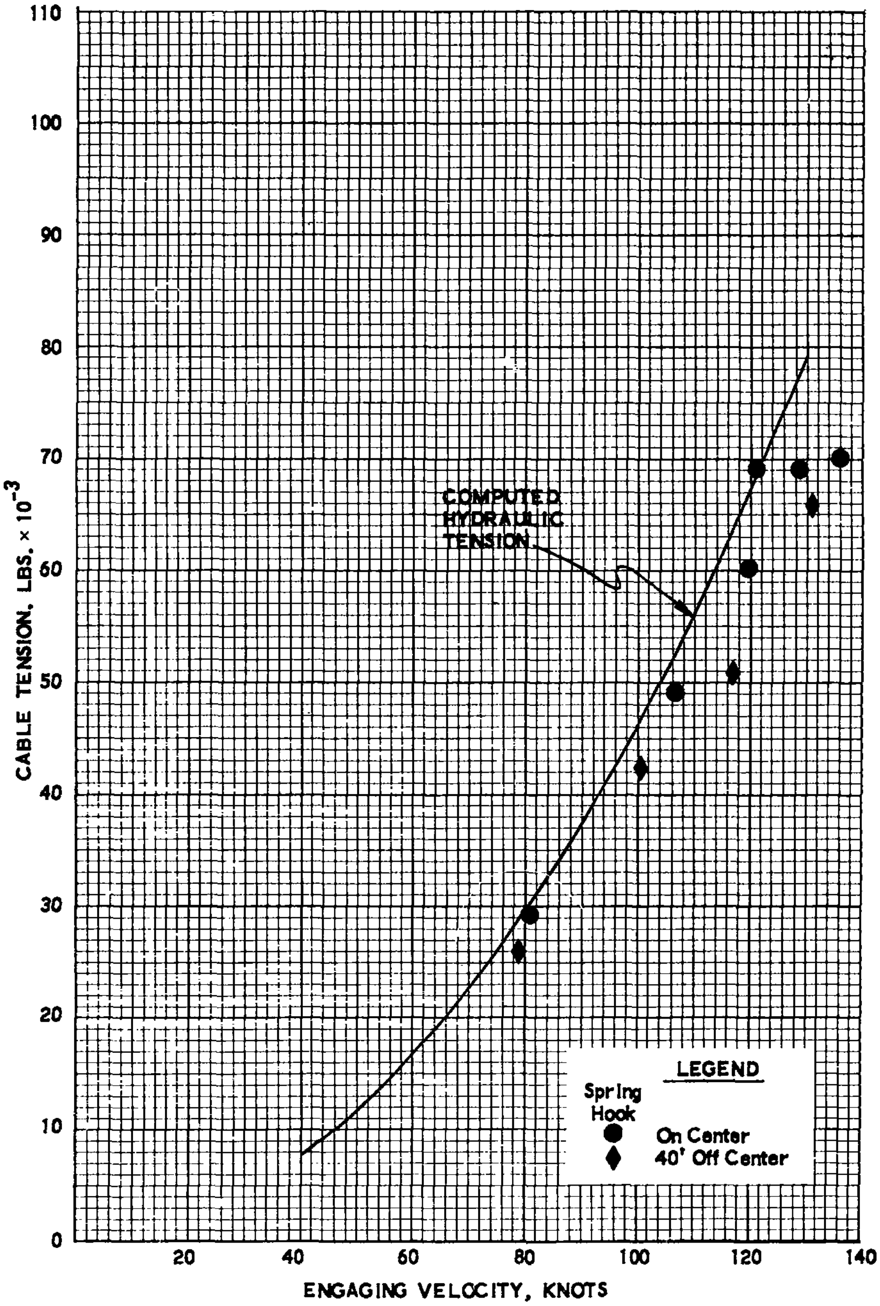


Figure 50 Maximum Hydraulic Cable Tension vs. Engaging Velocity, Boeing 720 at 135,000 Pounds

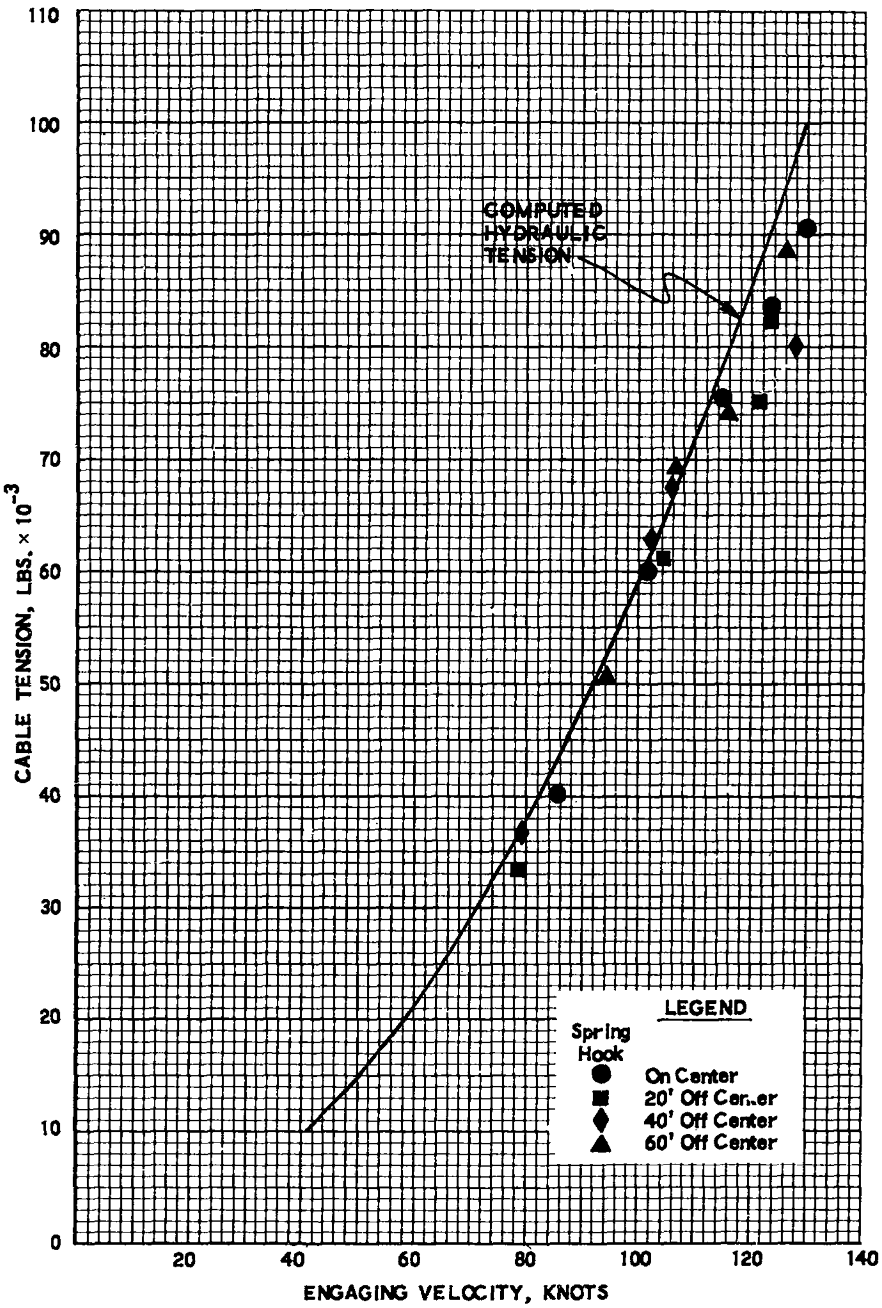


Figure 51 Maximum Hydraulic Cable Tension vs Engaging Velocity, Boeing 720 at 220,000 Pounds

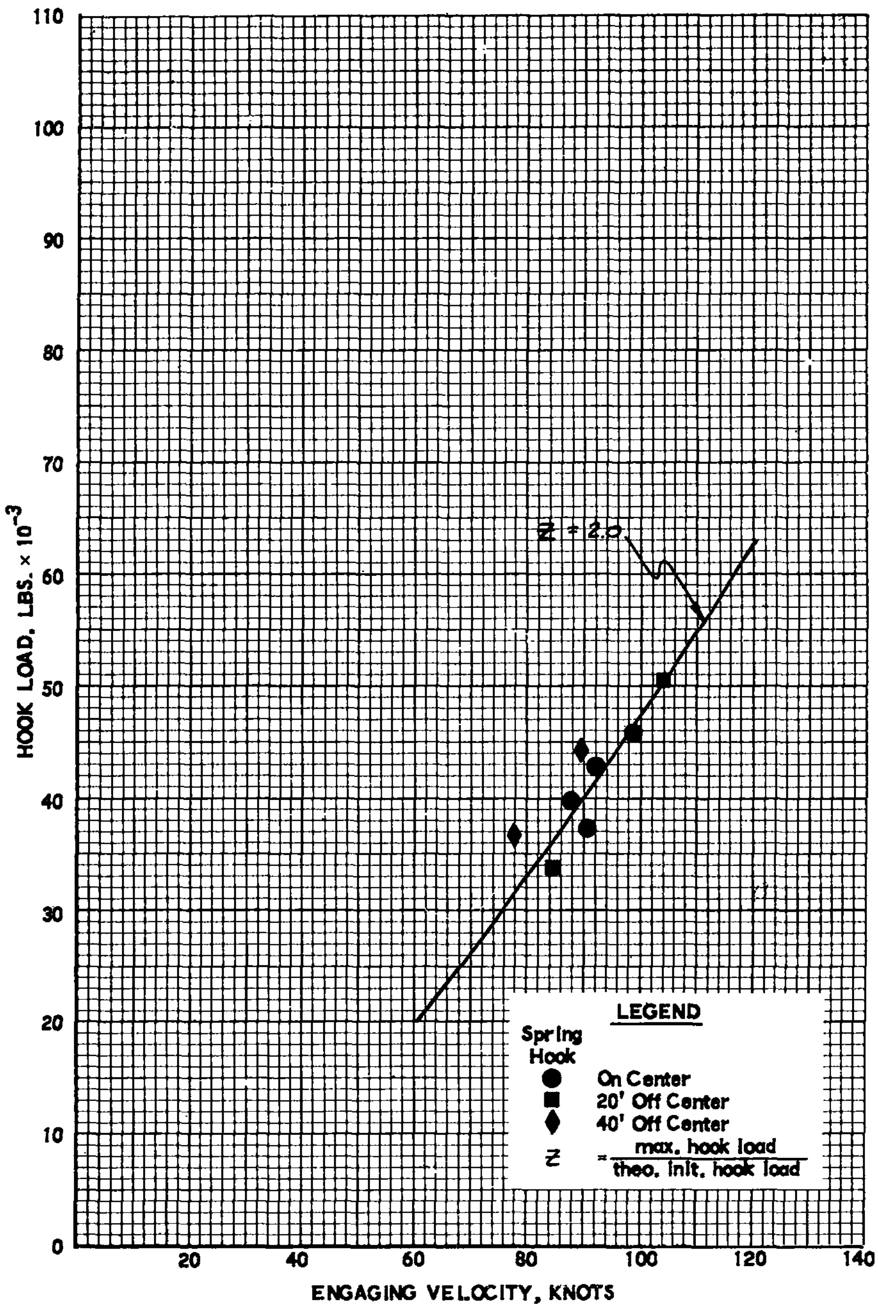


Figure 52 Maximum Dynamic Hook Load vs. Engaging Velocity, C-131B at 50,000 Pounds

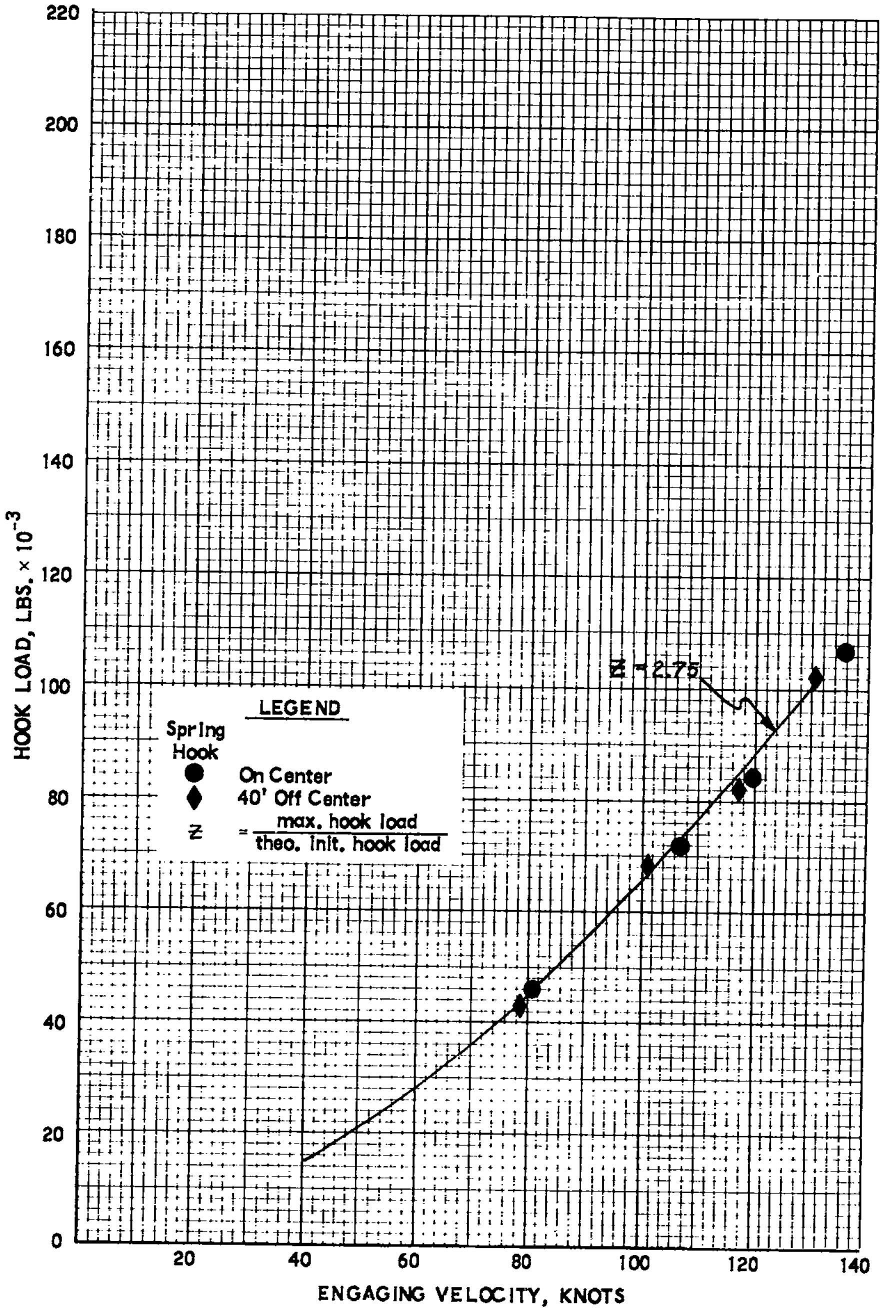


Figure 53 Maximum Dynamic Hook Load vs. Engaging Velocity, Boeing 720 at 135,000 Pounds

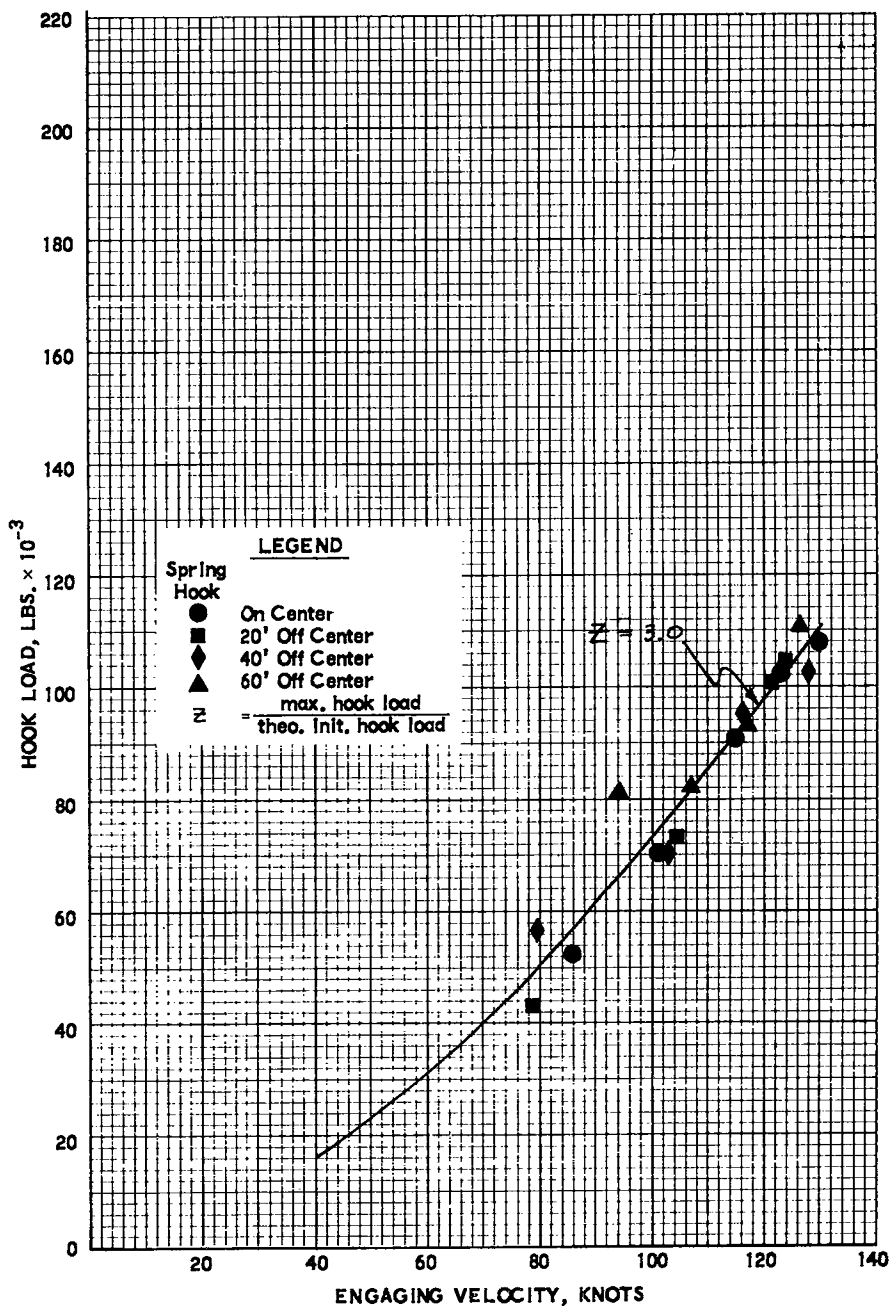


Figure 54 Maximum Dynamic Hook Load vs. Engaging Velocity, Boeing 720 at 220,000 Pounds

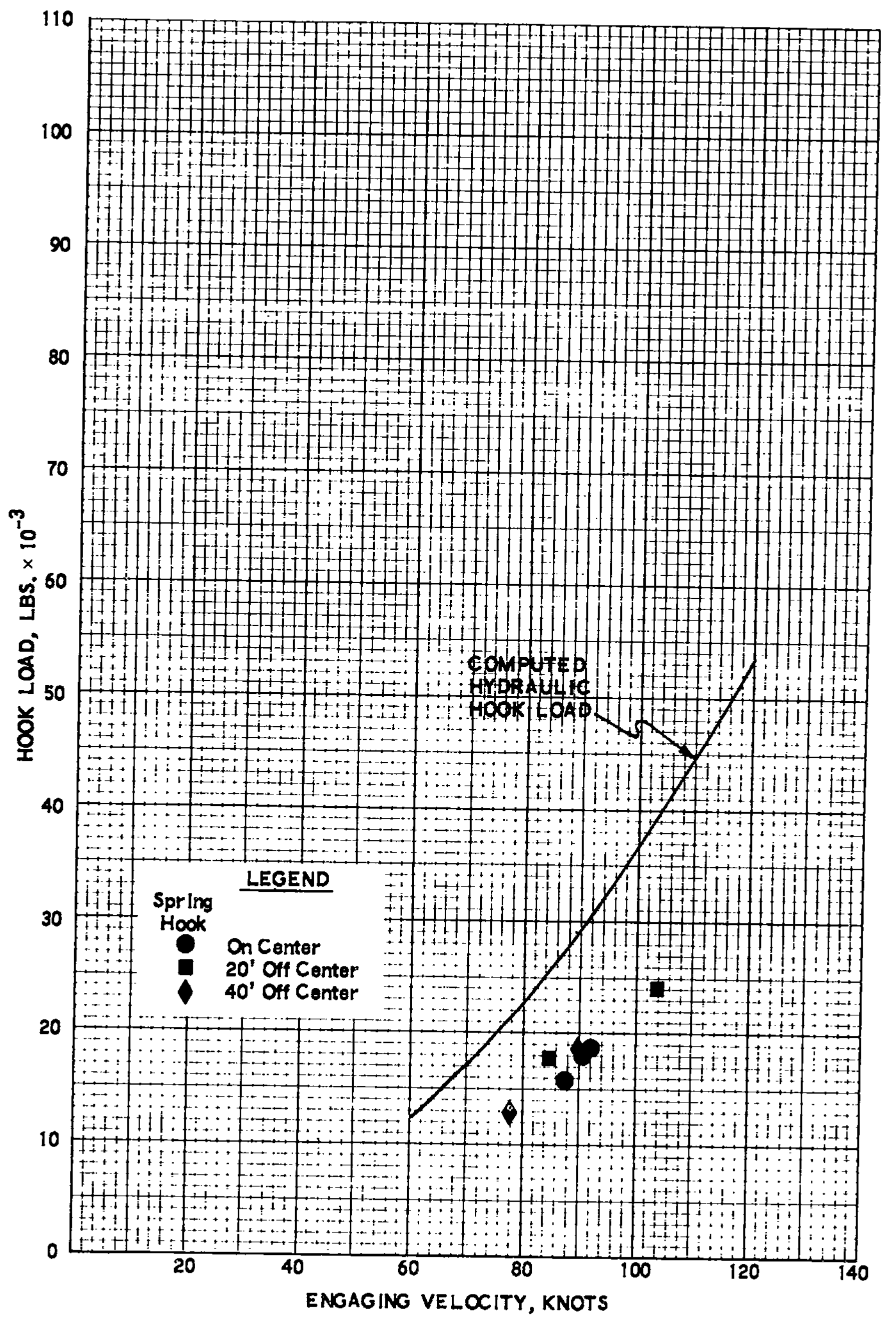


Figure 55 Maximum Hydraulic Hook Load vs. Engaging Velocity, C-131B at 50,000 Pounds

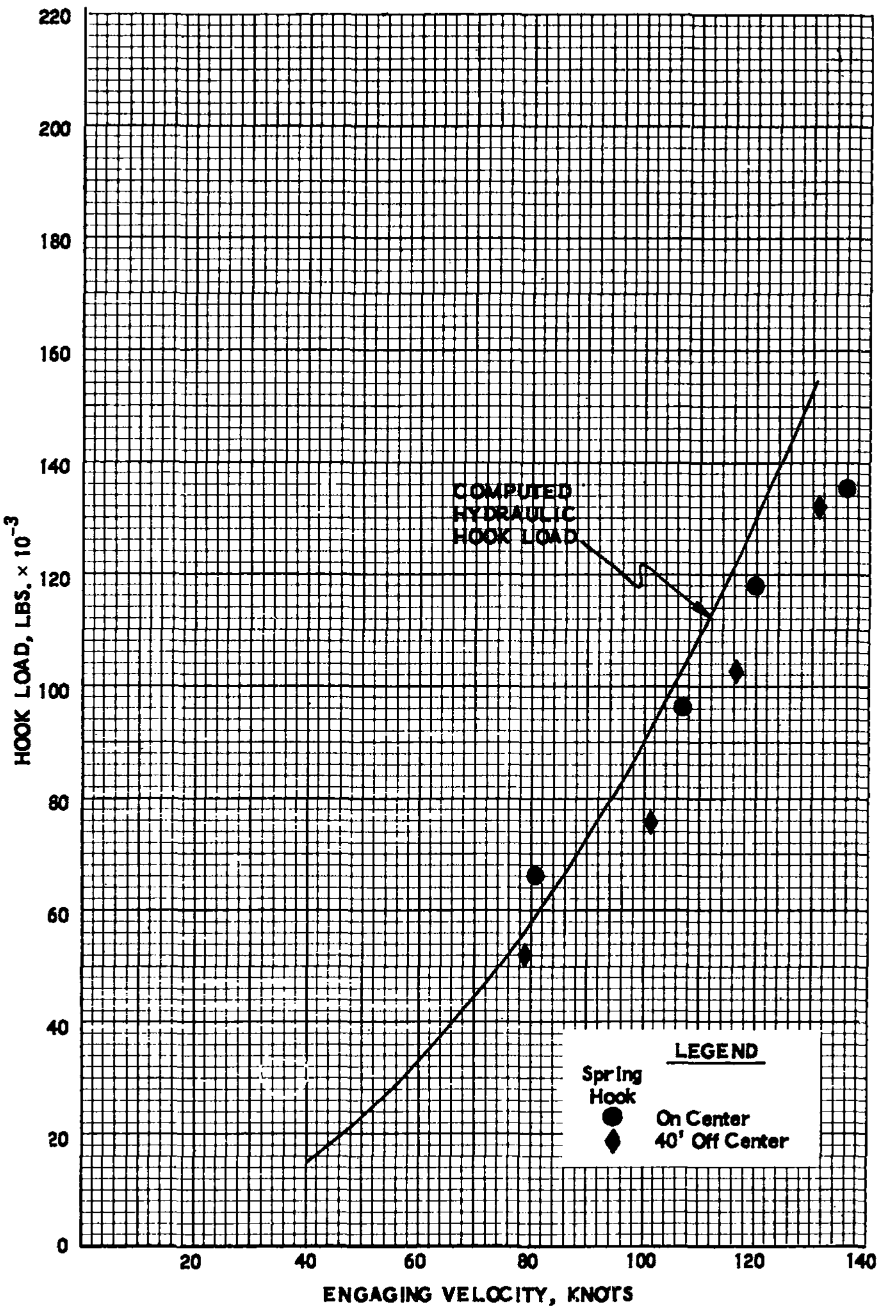


Figure 56 Maximum Hydraulic Hook Load vs. Engaging Velocity, Boeing 720 at 135,000 Pounds

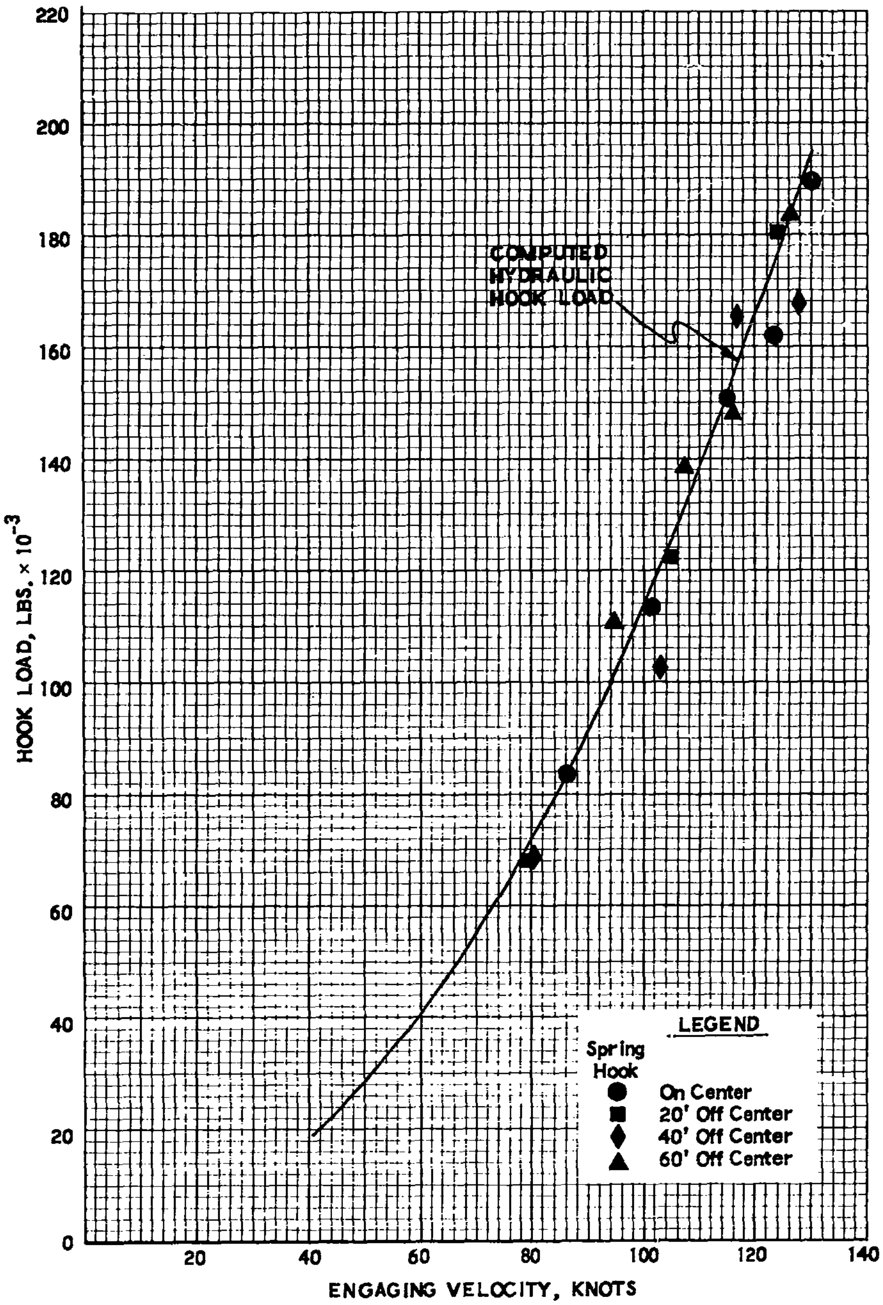


Figure 57 Maximum Hydraulic Hook Load vs. Engaging Velocity, Boeing 720 at 220,000 Pounds

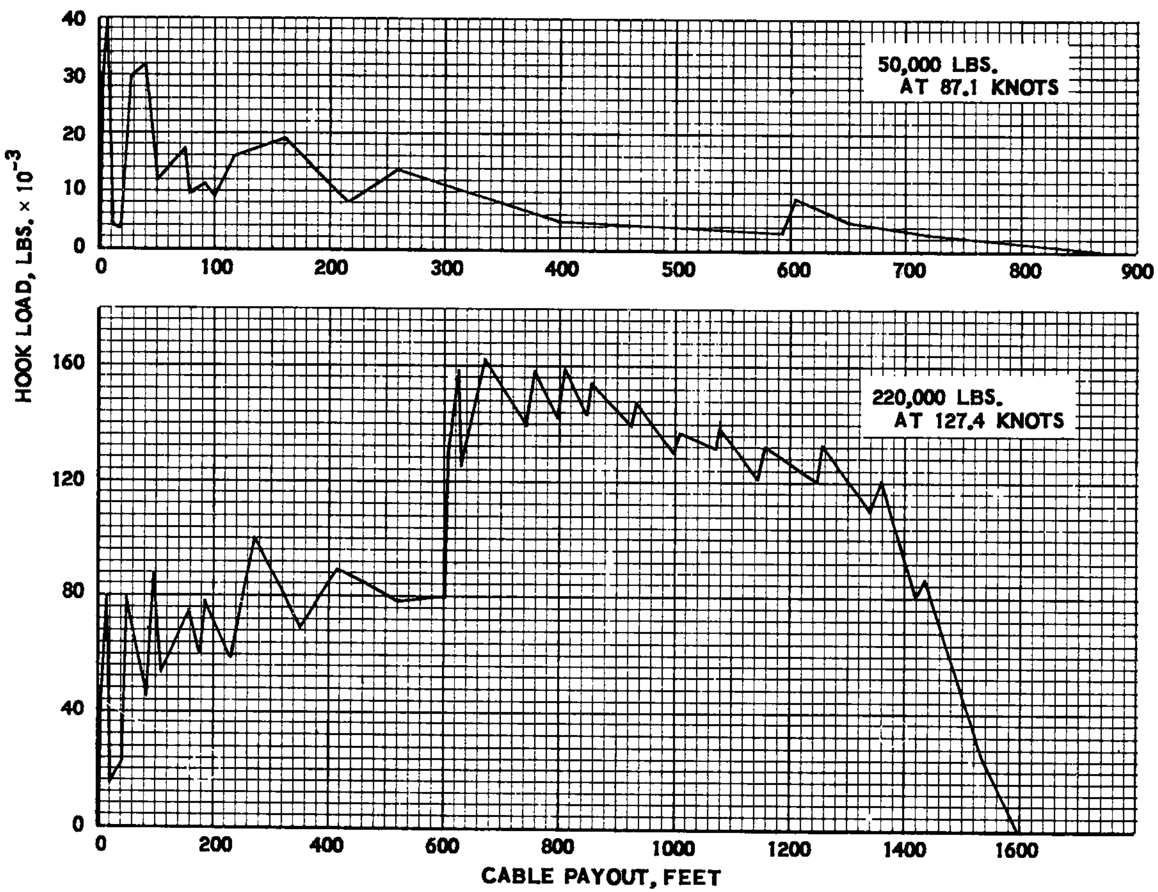


Figure 58 Hook Load vs. Cable Payout, Model 3500 Arresting Gear

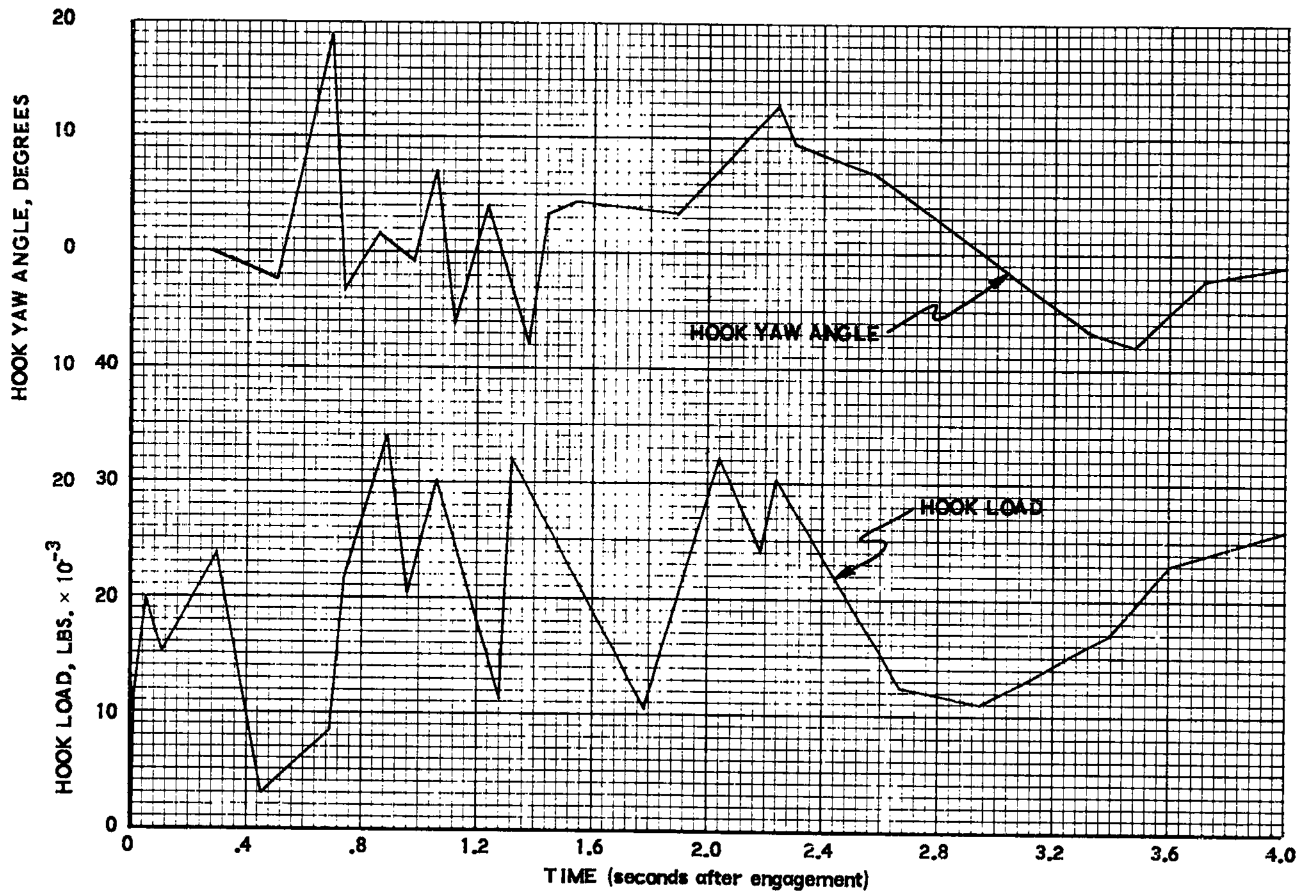


Figure 59 Hook Load and Hook Yaw Angle vs. Time, C-131B Arrestment (Typical 20 Feet Off-center)

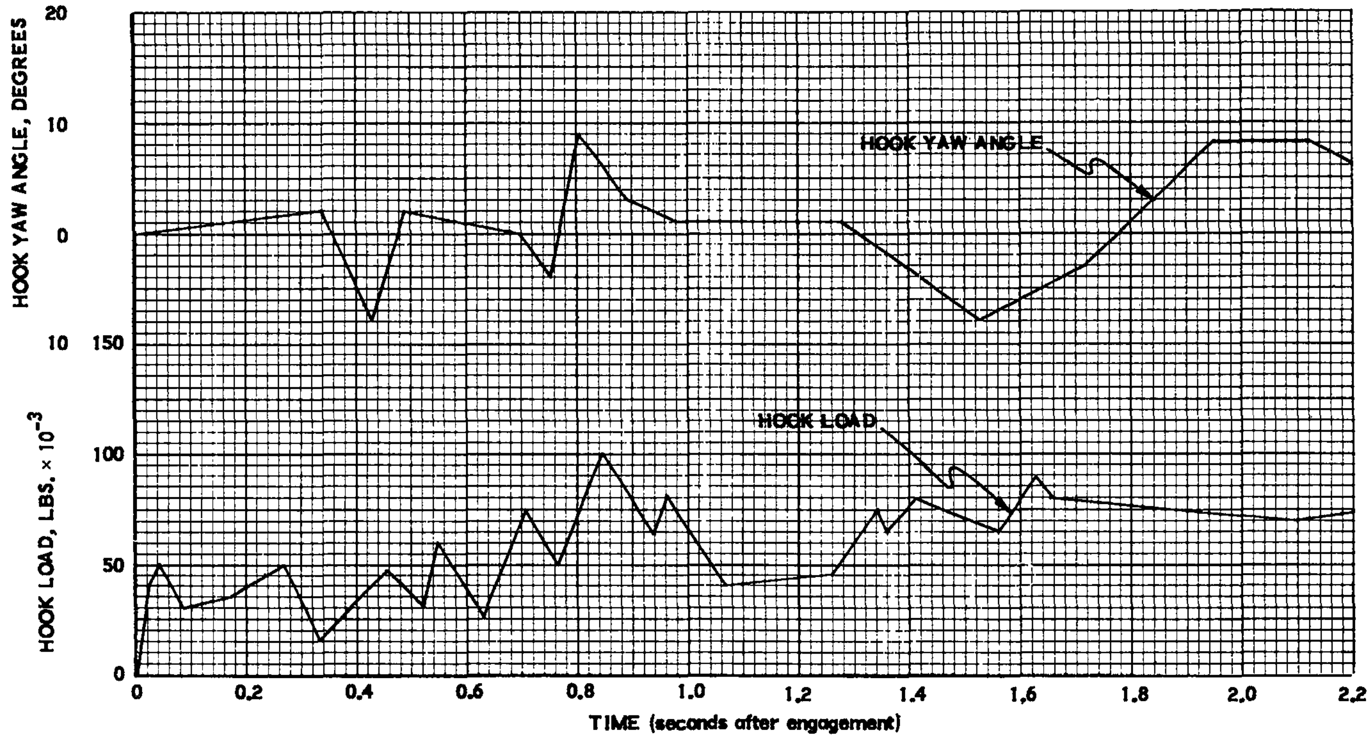


Figure 60 Hook Load and Hook Yaw Angle vs. Time, Boeing 720, 220,000-pound Arrestment (Typical 20 Feet Off-center)

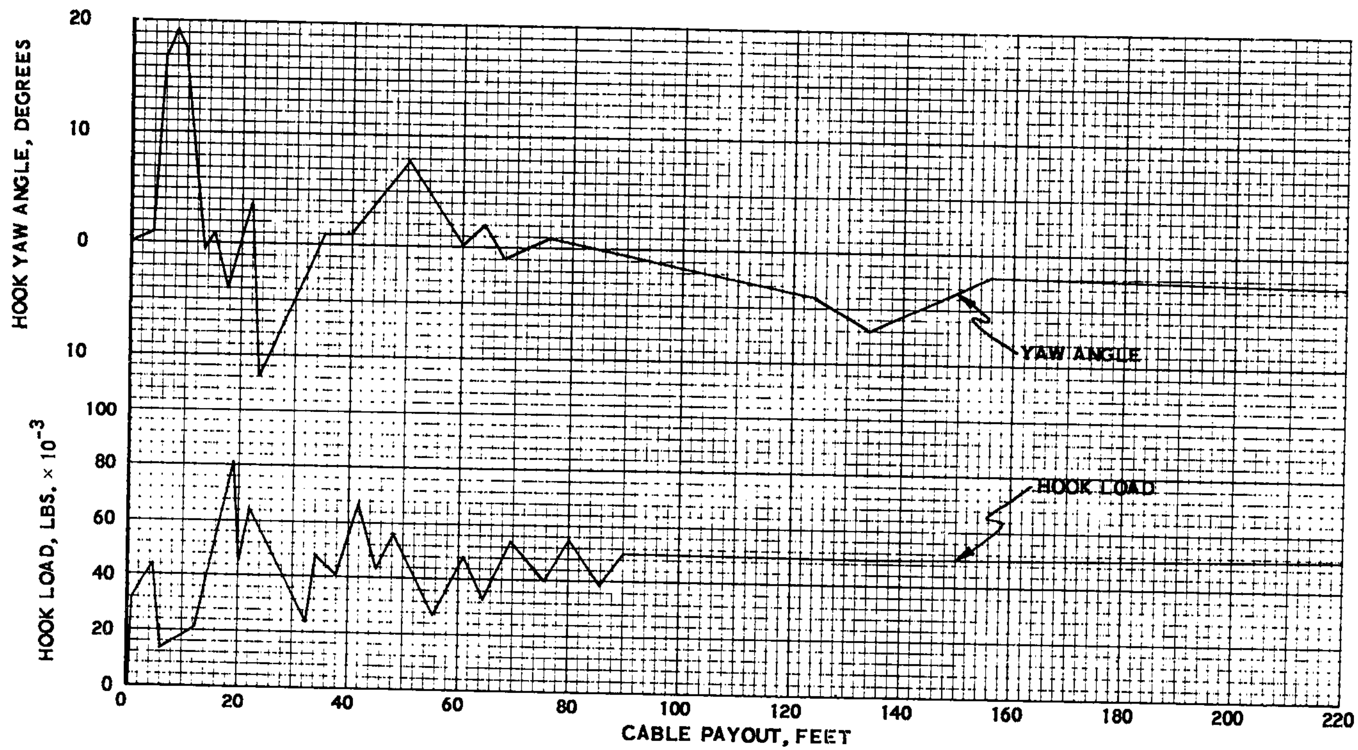


Figure 61 Hook Load and Hook Yaw Angle vs. Cable Payout, C-131B Arrestment (Typical 20 Feet Off-center)

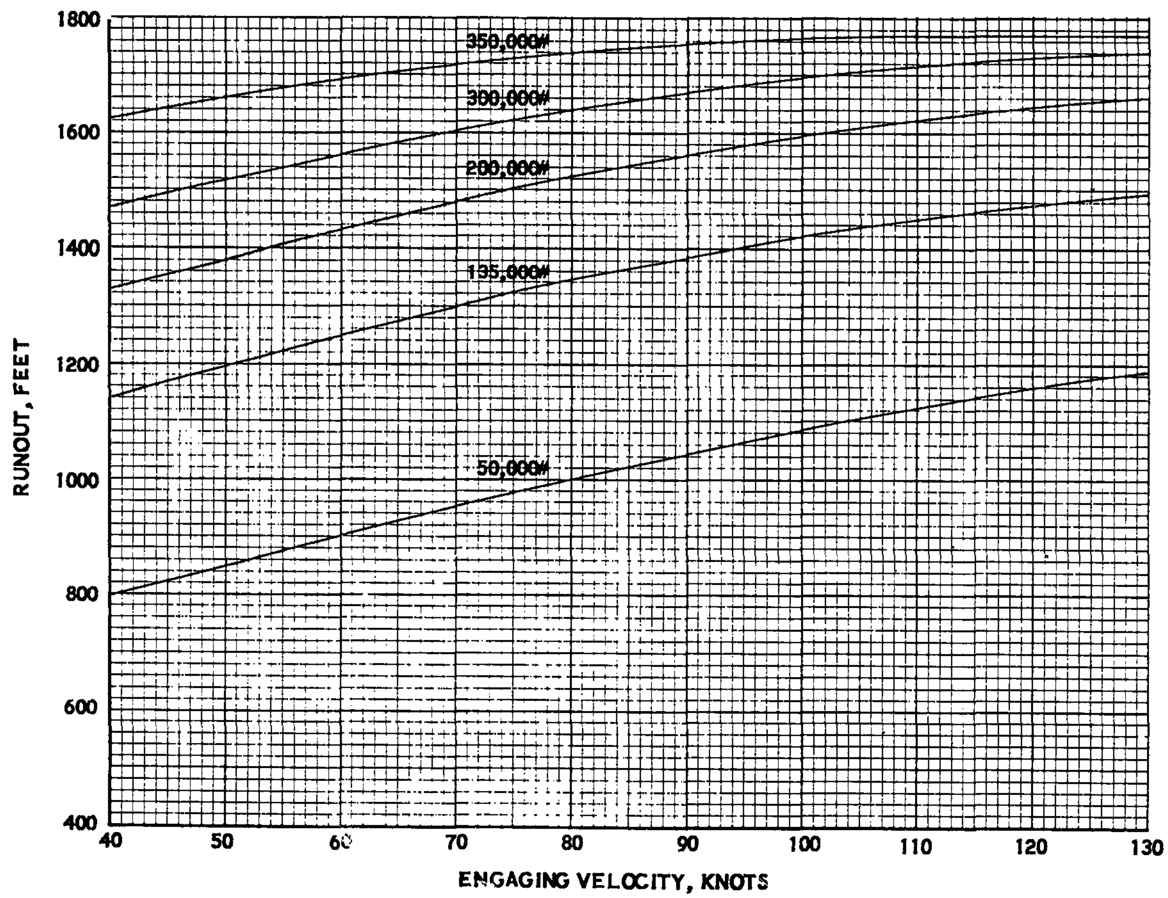


Figure 62 Runout vs. Engaging Velocity, Model 3500 Arresting Gear

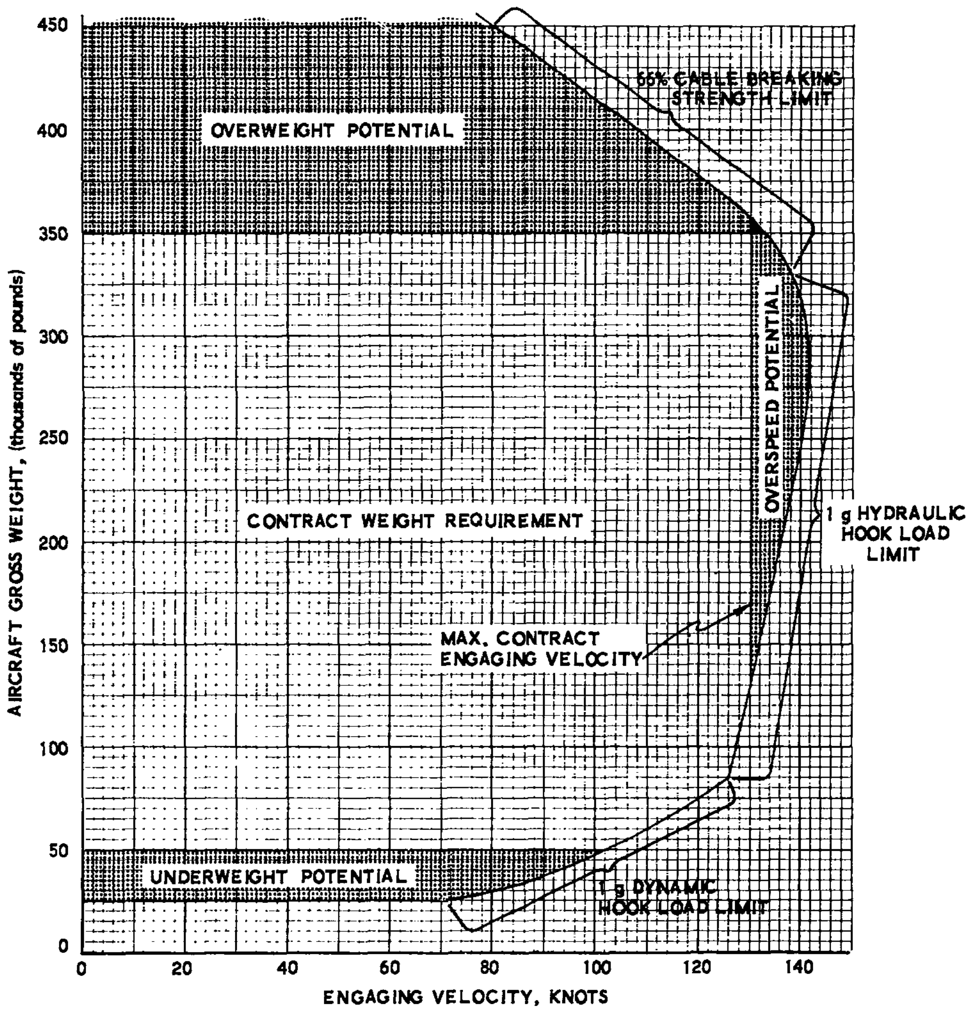


Figure 63 Performance Envelope, Model 3500 Arresting Gear

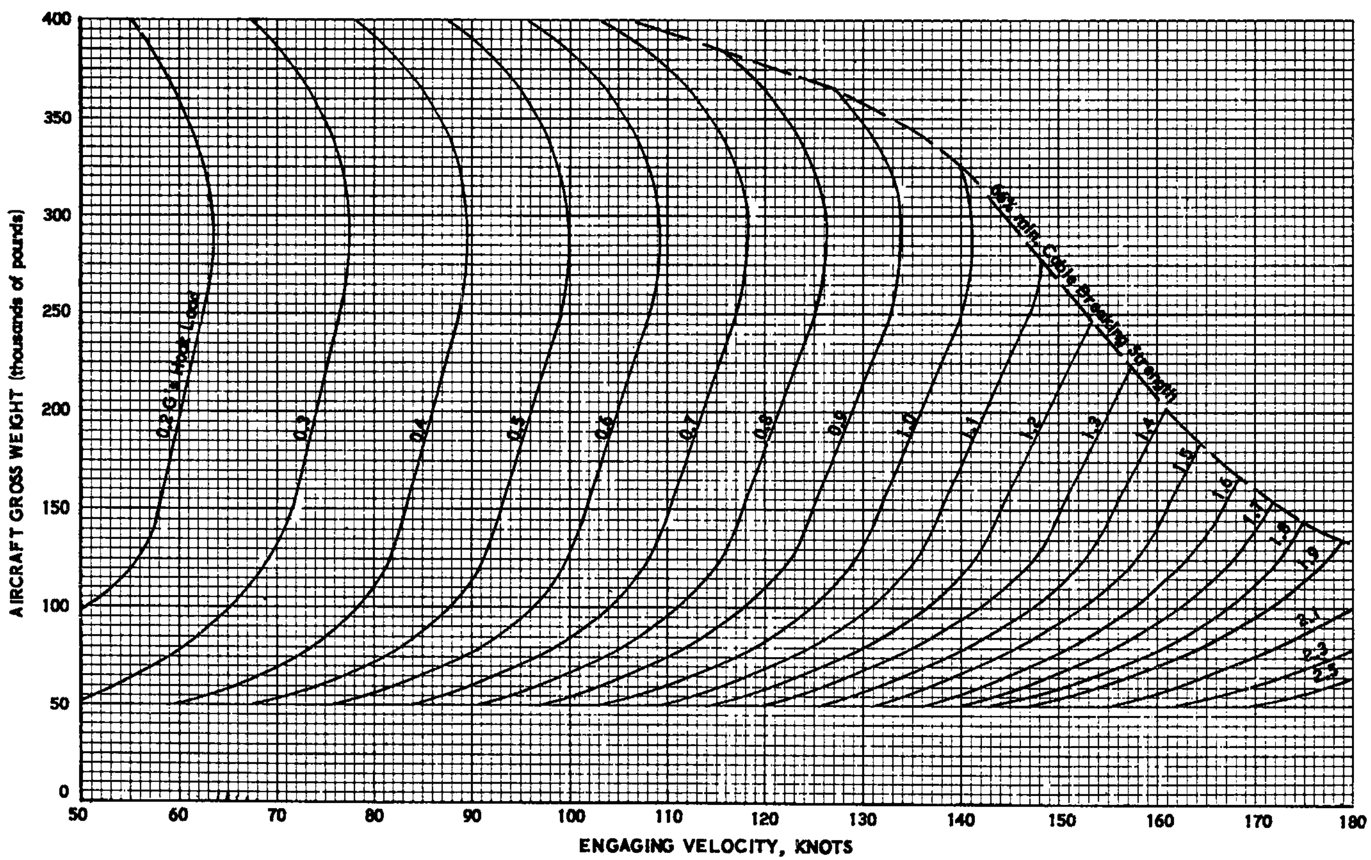


Figure 64 Hook Load Performance Curve, Model 3500 Arresting Gear

APPENDIX B

TEST PLANS

Form E-138 Page 1

ALL AMERICAN ENGINEERING COMPANY
WILMINGTON 99, DELAWARE

TEST PLAN - Revision C 9 April 1962

Project: Model 3500 Arresting Gear Location of Test: Georgetown, Delaware

Test Plan Number: 1476-1 Test Date: Beginning of April, 1962

Test Engineer: G. C. McIntosh ~~W. R. Schlegel~~ Overtime Authorized: ______

Sales Order Number: 1475 - Gear Testing ~~1476 - Instrumentat~~ion 1478 - FAA Launcher Operation

Prepared by: ______ Date: ______
W. C. Buckson

Approved by: M C Wardle John N Eustis 30 Mar 62
M. C. Wardle / J. N. Eustis Date: ______
(Project Manager)
W R Schlegel S ... 3/30/62
W. R. Schlegel / S. G. Keahey Date: ______
(Project Engineer)
W C Buckson 3/30/62
W. C. Buckson Date: ______
(Instrumentation)

______ Date: ______
(Contractor)

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SGKeahey (1 copy)
MCWardle (1 copy)
GCMcIntosh (1 copy)

TEST OBJECTIVES:

To determine the feasibility and establish the operation characteristics of a large capacity arresting gear (transport type) and to demonstrate the usefulness of a long stroke, low "g" acceleration launcher.

DESCRIPTION OF TEST COMPONENTS: (Include serial numbers where applicable.)

(1) Model 3500 Arresting Gear
(2) F. A. A. Launcher, modified for long stroke
(3) Three Large Dead Loads (DL-111, DL-112, DL-113)

TEST SEQUENCE OF EVENTS:

Event Number	Engaging Velocity	Weight	Number of Dead Loads
1	60 knots	50,000 pounds	1
2	80 knots	50,000 pounds	1
3	80 knots	50,000 pounds	1
4	100 knots	50,000 pounds	1
5	100 knots	50,000 pounds	1
6	40 knots	200,000 pounds	3
7	80 knots	200,000 pounds	3
8	100 knots	200,000 pounds	3
9	100 knots	200,000 pounds	3
10	120 knots	200,000 pounds	3
11	120 knots	200,000 pounds	3
12	130 knots	200,000 pounds	3
13	130 knots	200,000 pounds	3
14	80 knots	300,000 pounds	3
15	100 knots	300,000 pounds	3
16	100 knots	300,000 pounds	3
17	120 knots	300,000 pounds	3
18	120 knots	300,000 pounds	3
19	120 knots	300,000 pounds	3
20	120 knots	300,000 pounds	3
*			

NOTE 1: Acceptable limits on actual speeds as compared to predicted speeds are $\pm$ 10 knots.

NOTE 2: Test events will not be delayed or repeated for instrumentation, provided the items noted as contractually required are functioning properly.

NOTE 3: The above schedule of speeds may be varied at the discretion of the FAA Project Manager (Mr. F. J. Rhody) by written instructions. Total number of events to be the same, speed limitations to be 60-100 knots for 50,000 lb. series, not over 130 knots for 200,000 lb. series, and not over 120 knots for 300,000 lb. series. Events to be in order of increasing kinetic energy to allow monitoring of launcher performance.

* No test plan for test load engagements 21-30. Same instrumentation applies.

PHOTOGRAPHIC REQUIREMENTS:

Subject	Type of Coverage	Time of Action	Presentation Form
Pendant *(1)	Hi-Speed B&W 16MM	2-3 seconds	Movie
Arrestment (1)	Pan Color, 16MM	30 seconds	Movie
Installation	Still	------	Prints

*Camera should be elevated to show as much of the deck pendant as possible.

(1) Indicates items required by contract.

* Requires review of film.

PARAMETERS TO BE MEASURED:

Parameter	Location	Accuracy Required	Resolution Required	Maximum Value Anticipated
Arresting Gear				
Cable Tension T_2*	See Figure 1	4%	500 lbs.	180,000 pounds
Cable Velocity V_2*	See Figure	2%	0.5 rpm	210 rpm (220 ft./sec.)
Pressure* P_1 through P_4	See Figure 1	4%	20 psi	3,800 psi
Strain - S*	See Figure 1	5%	50 MI/I	700 MI/I
Dead Load Velocity V_3*	See Figure 1	2%	0.5 knots	130 knots
Dead Load				
Acceleration Load L_1	See Figure 2	4%	300 lbs.	90,000 pounds
Acceleration - A_1*	See Figure 2	4%	0.1 "g"	1 "g"
Hook Load - L_2*	See Figure 2	4%	800 lbs.	300,000 pounds
Deceleration - A_2*	See Figure 2	4%	0.1 "g"	3 "g"
Cable Slippage	Cable Grab relative to Cable	3%	1 inch	Unknown
Turbo-Cat				
Cable Tension* (slack side) T_3	See Figure 3	5%	50 lbs.	20,000 pounds
Cable Velocity - V_3	See Figure 3	2%	0.5 rpm	105 rpm (220 ft./sec.)
Capstan Velocity - V_4	See Figure 3	2%	0.25 rpm	105 rpm (220 ft., sec.)
Capstan in Balance ACC - A_3	See Figure 4	3%	0.1 "g"	4 "g"
Cable Tension (tight side) T_4	See Figure 3	4%	500 lbs.	100,000 pounds

PARAMETERS TO BE MEASURED:

Parameter	Location	Accuracy Required	Resolution Required	Maximum Value Anticipated
Turbo-Cat (continued):				
Cable Tension (slack side) T_5	See Figure 3	10%	500 lbs.	15 knots
Pretension Stroke ST_1	See Figure 3	3%	1 inch	12 feet
Time Correlation	Blips on Turbo-Cat and Dead Load Oscillographs	1%	N. A.	N. A.

DATA REQUIREMENTS:

Final Date Due: May 20, 1962

Parameter	Data Specifications	Presentation Format	Plotted on Same Graph
Arresting Gear			
Cable Tension	Port and Starboard; initial, dynamic, and hydraulic peaks	Tabulated versus Run	1
Hook Load	Port and Starboard; initial, dynamic, and hydraulic peaks	Tabulated versus Run	1
Dead Load Acceleration	Port and Starboard; initial, dynamic, and hydraulic peaks	Tabulated versus Run	1
Dead load Weight	-----	Tabulated versus Run	1
Pressure	Peak Value	Tabulated versus Run	1
Runout	-----	Tabulated versus Run	1
Engaging Velocity	-----	Tabulated versus Run	1
Strain	Peak Value	Tabulated versus Run	1
**Tension		Plotted versus Payout Energy Integral	2
T-Cat			
Acceleration Load	Peak Value	Tabulated versus Run	3
Capstan Velocity	Peak Value	Tabulated versus Run	3
Cable Velocity	Read at same instant in time as Capstan Velocity	Tabulated versus Run	3
Capstan Acceleration	Peak Value	Tabulated versus Run	3
**First Eight Runs, Project Engineer	then only as requested by the		

BY	DATE	SUBJECT	TRANSDUCER LOCATIONS	SHEET NO.	OF
CHKD. BY	DATE			JOB NO.	

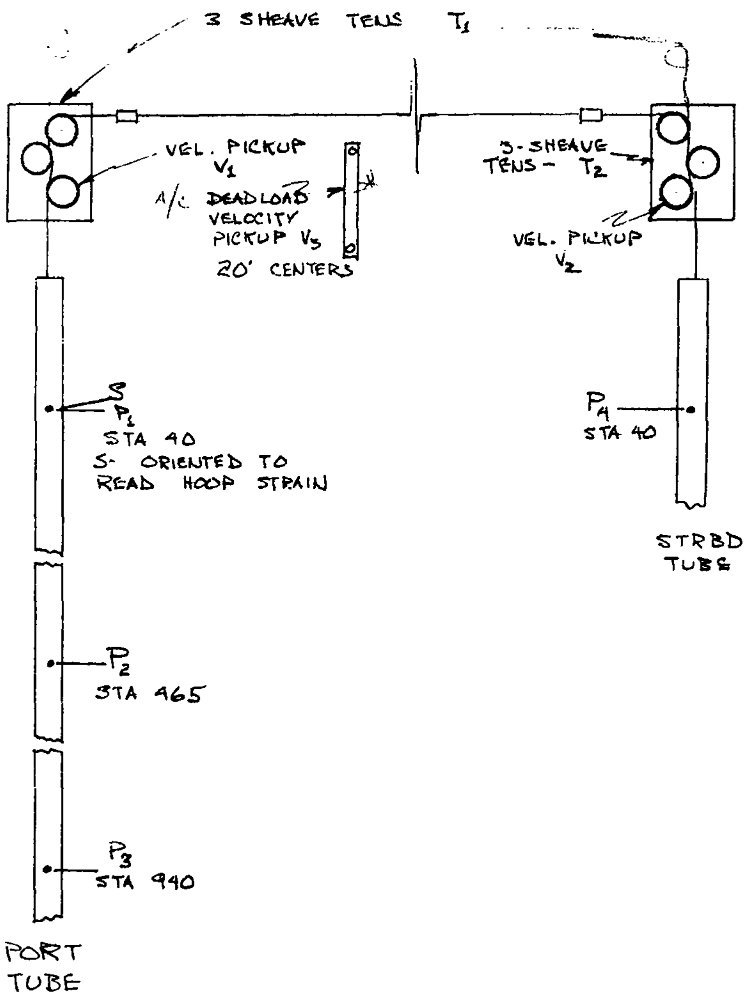
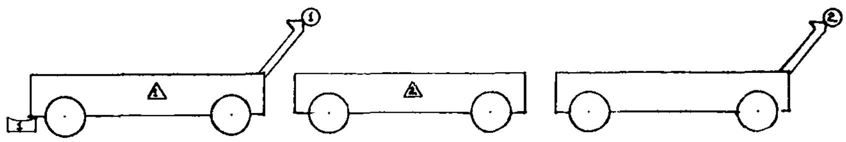


FIG 1 (REV.)

TRANSDUCER LOCATIONS



INSTRUMENTS WILL ALWAYS BE LOCATED IN DEAD LOAD #111

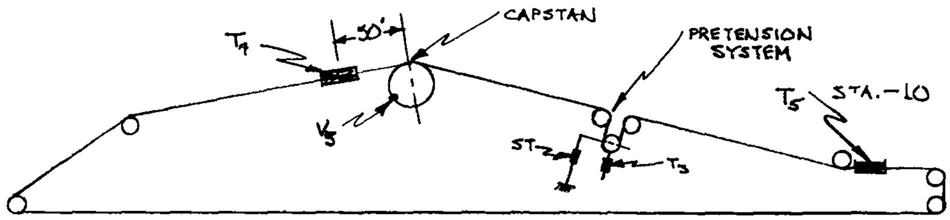
[1] - LOCATION OF LOAD LINK, L_1, DURING ALL TESTS.

△ - LOCATION OF ACC, A_1 & A_2, WITH ONE DEAD LOAD
▲ - " " " " THREE " " .

① - LOCATION OF INST'D HOOK WITH ONE DEAD LOAD.
② - " " " " " THREE DEAD LOADS.

FIG. 2

BY......DATE......	SUBJECT TRANSDUCER LOCATIONS	SHEET NO......OF......	
CHKD. BY......DATE......		JOB NO......	



T_3 – SLACK SIDE CABLE TENSION; LOAD LINK IN SERIES WITH MOVEABLE SHEAVES. ACTUAL LOAD ON LOAD IS FOUR TIMES CABLE TENSION.

T_4 – TIGHT SIDE CABLE TENSION; 3-SHEAVE TENSIOMETER

T_5 – SLACK SIDE CABLE TENSION; 3-SHEAVE TENSIOMETER

V_3 – CAPSTAN VELOCITY; COIL & MAGNET

ST – PRETENSION SYSTEM STROKE MEASUREMENT; POT ATTACHED TO MOVEABLE SHEAVES.

FIG 3 (REV)

TRANSDUCER LOCATIONS

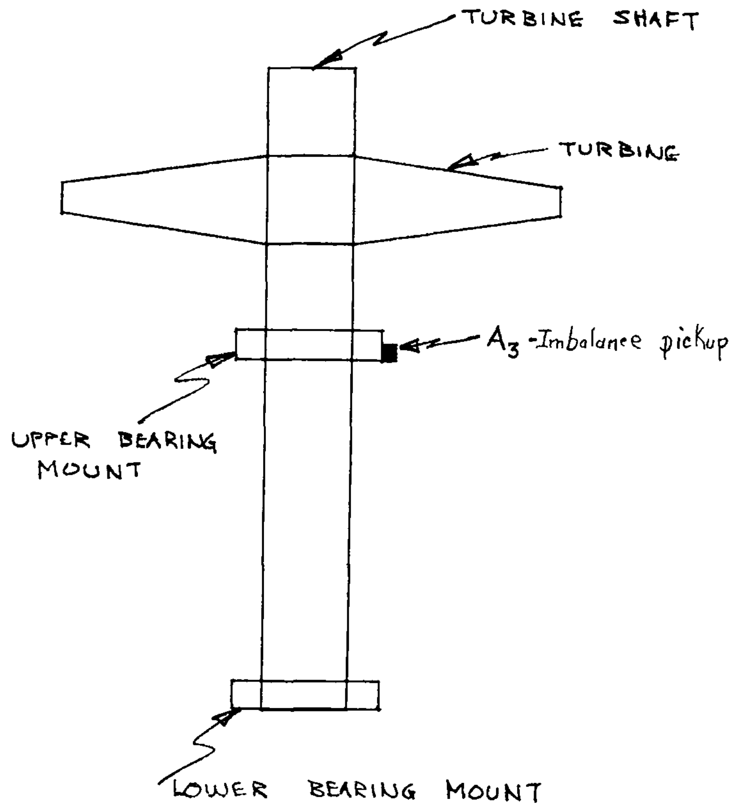


FIG 4.

Form E-138

ALL AMERICAN ENGINEERING COMPANY
WILMINGTON 99, DELAWARE

TEST PLAN - REVISION A

Project: Model 3500 Arresting Gear Location of Test: Georgetown, Delaware

Test Plan Number: 1476-2 Test Date: Begin the Week of 6 August 1962

Test Engineer: G. C. McIntosh W. R. Schlegel Overtime Authorized:

Sales Order Number: 1485-115 (Gear) 1485-116 (Dead Load and Launcher)

Prepared by: W. C. Buckson W. R. Schlegel Date: 7/26/62

Approved by:

	Date	Distribution
(Project Manager)	8-2-62	JNEustis 1
McWardle S. G. Keahey (Project Engineer)	8/3/62	WRSchlegel 2
W. C. Buckson (Instrumentation)	7/27/62	MCWardle 1
R. Rhody (FAA Project Manager)	9-5-62	SGKeahey 1
		WJNissley 2
		WCBuckson 3
		FMHighley 1

TEST OBJECTIVES:

To determine the off-center engaging and arresting capabilities of the Model 3500 Arresting Gear

DESCRIPTION OF TEST COMPONENTS: (Include serial numbers where applicable.)

(1) Model 3500 Arresting Gear
(2) Federal Aviation Agency Launcher Modified for Long Stroke
(3) Three (3) Large Dead Loads (Dead Load 111, Dead Load 112, and Dead Load 113)
(4) Off-Center Sheave Pads to Allow Simulation of Various Off-Center Configurations

"Revisions to the original plan are indicated by vertical black lines on right hand border."

TEST SEQUENCE OF EVENTS:

Event Number	Engaging Velocity	Weight	Off-Center Distance
31	125 Knots	200K pounds	20 feet
32	130 knots	200 K pounds	20 feet
33	130 knots	200K pounds	20 feet
34	108 knots	200K pounds	40 feet
35	115 knots	200K pounds	40 feet
36	120 knots	200K pounds	40 feet

NOTE: Beginning with Run 38 through Run 45, peak cable tensions will be checked to determine at what engaging velocity a tension equal to 66 per cent of the cable breaking strength is experienced. If this velocity is less than the 120 knots planned for the 60-foot off-center shots, then the maximum permissible velocity shot will be repeated. Should there be any shots not completed in the series 38 through 45 because of the maximum tensions experienced, then the remaining shots in the series will be made at **the discretion of the FAA Project Manager.**

Event Number	Engaging Velocity	Weight	Off-Center Distance
37	85 knots	200K pounds	60 feet
38	90 knots	200K pounds	60 feet
39	95 knots	200K pounds	60 feet
40	100 knots	200K pounds	60 feet
41	105 knots	200K pounds	60 feet
42	110 knots	200K pounds	60 feet
43	115 knots	200K pounds	60 feet
44	120 knots	200K pounds	60 feet
45	120 knots	200K pounds	60 feet
46 *	120 knots	300K pounds	60 feet
47 **	120 knots	300K pounds	20 feet
48 ***	85 knots	50K pounds	60 feet
49	95 knots	50K pounds	60 feet
50	95 knots	50K pounds	20 feet

* or highest speed to reach 66% CBS as predicted from 200K pound series.

** or highest speed attainable with launcher.

*** or at whatever speed zero relief occurs in dynamics from 200K pound series.

NOTE: At the discretion of the FAA Project Manager, an All American Engineering Company designed 720 or 707 spring hook will be substituted for the standard dead load hook, with the standard hook used as a back-up.

PHOTOGRAPHIC REQUIREMENTS:

Subject	Type of Coverage	Time of Action	Presentation Form
Pendant * (1)	Hi-Speed B&W 16MM	2-3 seconds	Movie
Arrestment (1)	Pan Color, 16MM	30 seconds	Movie
Installation	Still	------	Prints

*Camera should be elevated to show as much of the deck pendant as possible.

(1) Indicates items required by contract.

* Requires review of film.

PARAMETERS TO BE MEASURED:

Parameter	Location	Accuracy Required	Resolution Required	Maximum Value Anticipated
Arresting Gear				
Cable Tension T_1* and T_2	See Figure 1	4%	500 pounds	180,000 pounds
Cable Velocity V_1* and V_2	See Figure 1	2%	0.5 rpm	210 rpm (220 feet per second)
Pressure - P_1 through P_4	See Figure 1	4%	20 psi	3,800 psi
Dead Load Velocity V_3*	See Figure 1	2%	0.5 knots	130 knots
Dead Load				
Acceleration Load L_1	See Figure 2	4%	300 pounds	90,000 pounds
Acceleration - A_1*	See Figure 2	4%	0.1 "g"	1 "g"
Hook Load - L_2*	See Figure 2	4%	800 pounds	300,000 pounds
Deceleration - A_2*	See Figure 2	4%	0.1 "g"	3 "g"
Cable Slippage	See Figure 2	3%	1 inch	Unknown
Time Correlation	Blips on Launcher and Dead Load Trace	1%	N/A	N/A
** Hook Rotation	Hook Rotation Center	3%	0.5 deg.	$\pm$ 25 degrees
Turbo-Cat				
Cable Velocity - V_4	See Figure 3	2%	0.5 rpm	105 rpm (220 feet per second)
Capstan Velocity - V_5	See Figure 3	2%	0.25 rpm	105 rpm
Capstan Imbalance	See Figure 4	3%	0.1 "g"	4 "g"
Cable Tension * (Slack Side) T_3	See Figure 3	5%	50 pounds	20,000 pounds
Pretension Stroke - ST_1	See Figure 3	3%	1 inch	12 feet
Time Correlation	Blips on Launcher and Dead Load Trace	1%	N/A	N/A

* Indicates items required by contract.

NOTE: Cable slippage measurement may be eliminated at the discretion of the Test Engineer.

** To be measured only when a spring hook is installed on the dead load.

DATA REQUIREMENTS:

Final Data Due: 15 November 1962

Parameter	Data Specifications	Presentation Format	Plotted on Same Graph
Arresting Gear			
Cable Tension	Port or Starboard; initial, dynamic, and hydraulic peaks	Tabulated versus Run	1
Hook Load	Initial, dynamic, and hydraulic peaks	Tabulated versus Run	1
Dead Load Acceleration	Initial, dynamic, and hydraulic peaks	Tabulated versus Run	1
Dead Load Weight	-----	Tabulated versus Run	1
Pressure	Peak Value	Tabulated versus Run	1
Runout	-----	Tabulated versus Run	1
Engaging Velocity	-----	Tabulated versus Run	1
*Cable Tension		Plotted versys Payout Energy Integral	2
T-Cat			
Acceleration Load	Peak Value	Tabulated versus Run	3
Capstan Velocity	Peak Value	Tabulated versus Run	3
Cable Velocity	Read at same instant in time as Capstan Velocity	Tabulated versus Run	3
Capstan Acceleration	Peak Value	Tabulated versus Run	3

* First Eight Runs, then only as requested by the Project Engineer

BY............DATE.......... SUBJECT TRANSDUCER LOCATIONS SHEET NO.........OF.....
CHKD. BY......DATE.......... JOB NO...................

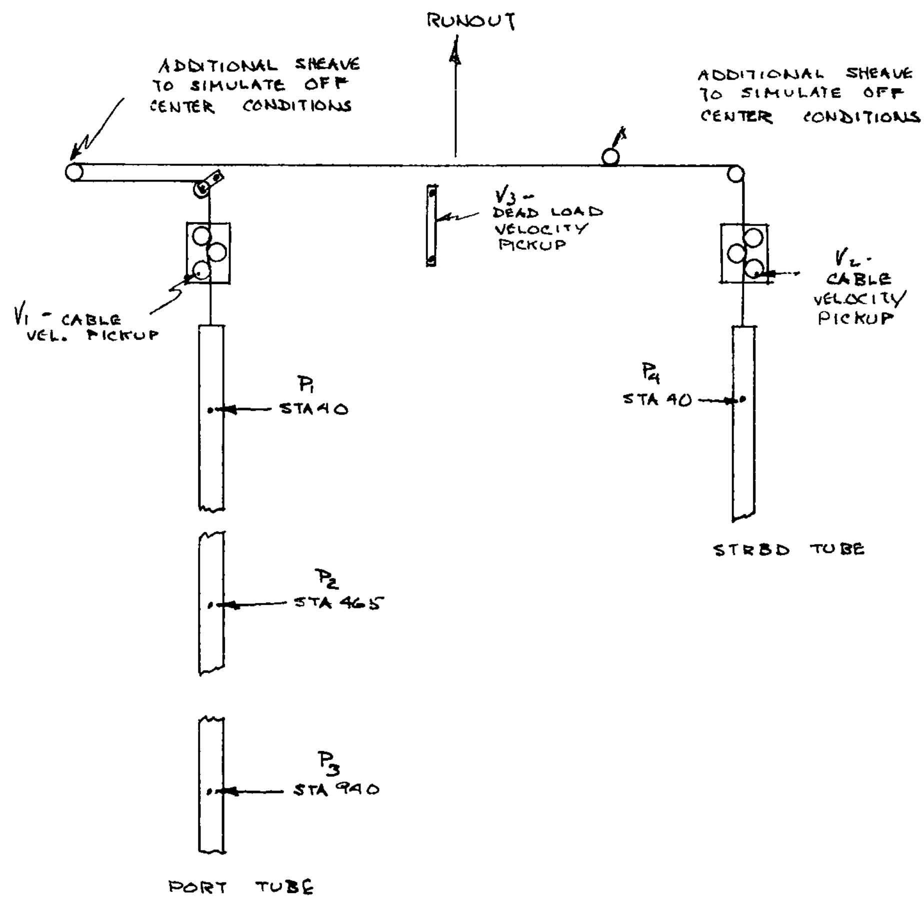
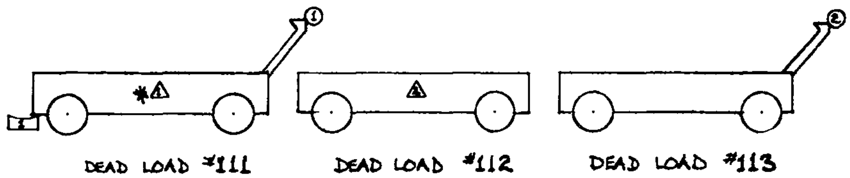


FIG. 1

TRANSDUCER LOCATIONS



INSTRUMENTS WILL ALWAYS BE LOCATED IN DEAD LOAD #111

- LOCATION OF LOAD LINK, L_1, DURING ALL TESTS.

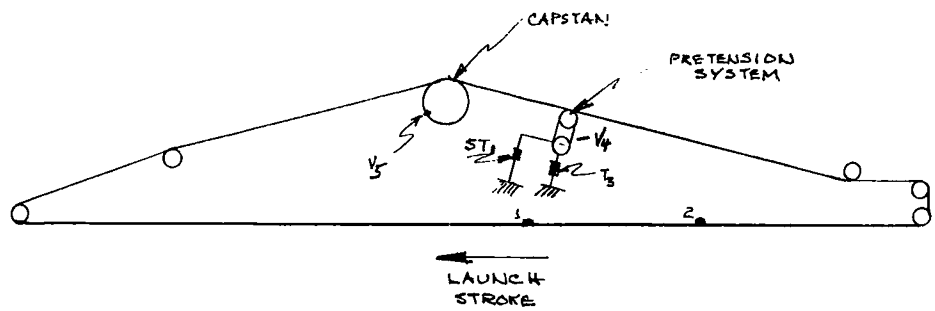
△ - LOCATION OF ACC, A_1 & A_2, WITH ONE DEAD LOAD
▲ - " " " " THREE " " .

1 - LOCATION OF INST'D HOOK WITH ONE DEAD LOAD.
2 - " " " " " THREE DEAD LOADS.

* - LOCATION OF CABLE SLIPPAGE MEASUREMENT; MEASUREMENT MADE RELATIVE TO DEAD LOAD.

FIG. 2

BY.......DATE.......	SUBJECT TRANSDUCER	SHEET NO.......OF.....
CHKD. BY.......DATE.......	LOCATIONS	JOB NO........



1 & 2 TIME CORRELATION FOR DEAD LOAD & LAUNCHER OSCILLOGRAPHS.

T_3 - SLACK SIDE CABLE TENSION; LOAD LINK IN SERIES WITH MOVEABLE SHEAVES ON PRETENSION SYSTEM. ACTUAL LOAD ON LINK IS FOUR TIMES CABLE TENSION.

V_5 - CAPSTAN VELOCITY; COIL & MAGNET.

ST_1 - PRETENSION SYSTEM STROKE MEASUREMENT; POT ATTACHED TO MOVEABLE SHEAVES.

V_4 - Cable Velocity; magnet + coil

FIG. 3

TRANSDUCER LOCATIONS

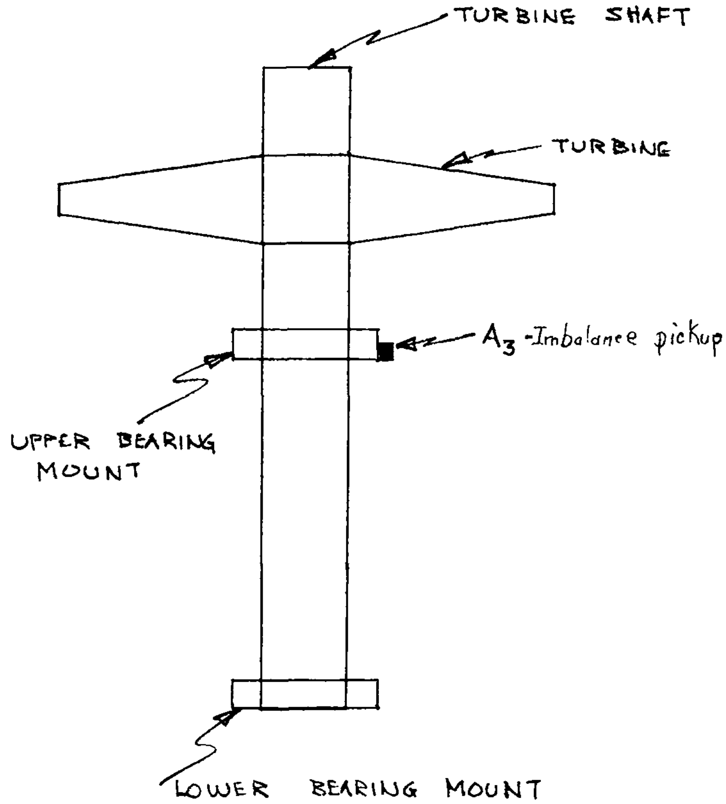


FIG 4.

ALL AMERICAN ENGINEERING COMPANY
WILMINGTON 99, DELAWARE

TEST PLAN

Project: Model 3500 Arresting Gear Location of Test: Georgetown, Delaware

Test Plan Number: 1476-3 Test Date: Commence: Week of 27 August 1962

Test Engineer: W. R. Schlegel Overtime Authorized:

Sales Order Number: 1485-441

Prepared by: W. C. Buckson Date:

Approved by:

(Project Manager) Date: 8-28-62

(Project Engineer) Date:

(Instrumentation) Date: 8/27/62

(FAA Project Manager) Date: 9-5-62

Distribution:

WCCollins (6)
WRSchlegel (2)
MCWardle (1)
WJNissley (2)
WCBuckson (3)

TEST OBJECTIVES:

To determine the bounce and the cable engaging characteristics of All American Engineering Company's 720 tail hook (original design)

DESCRIPTION OF TEST COMPONENTS: (Include serial numbers where applicable.)

(1) All American Engineering Company 720 Tail Hook
(2) Federal Aviation Agency Launcher Modified for Long Stroke
(3) Three Large Dead Loads (Dead Load 111, 112, and 113)

TEST SEQUENCE OF EVENTS:

Event Number	Event Description
A, B, C,	During the deadload run start camera and release the hook at station 1000; simulated cable pick-up at station 1200 and 1300. Ramp obstacle at station 1600 (ramp to face hook - sharp edge first 1-1/2 inches in height and 12 inches long). Simulated cable pick-up at station 1600 and station 1800. Ramp obstacle at station 2200 (1-1/2" x 24") with simulated cable pick-up at station 2200 and 2400
D, E, F,	Same as A, B, C except 1st ramp to be 24 inches long and second ramp 36 inches long.
G, H, I,	Same as A, B, C except 1st ramp to be 48 inches long and second ramp 60 inches long.
J, K, L, M,	Release hook at 1000' and run the hook over obstacles representing center line lights located at station 1400, 1425, 1450, and 1475 (6" dia. light) simulated cable pick-up at station 1435 and station 1495. Second series of light obstacles (8" dia. light) to be located at station 2000, 2025, 2050, and 2075 with simulated cable pick-up at station 2035, and 2095. Ramp configured as shown best from runs A-I at station 2200 with simulated cable pick-up at station 2035 and 2095.
N, O,	Release hook at station 1000 with representative concrete slab off-set of 1/2" at station 2300 and simulated cable pick-up at station 2400. Representative slab off-set of 3/4" at station 2600 with simulated cable pick-up at station 2700. Cut in runway surface two inches wide by 2 inches deep at station 1700. Simulated cable pick-up at stations 1800, 2000, and 2400.
P, Q.	Reserved for runs dependant on results of previous runs. NOTE: Runway to be marked with distance marks from station 1000 to station 3000 at 100 foot intervals. Stations for ramps and cable pick-ups may be altered as directed by the Project Manager during test series as determined necessary from test data.

PHOTOGRAPHIC REQUIREMENTS:

Subject	Type of Coverage	Time of Action	Presentation Form
Hook Release	B&W Movie standard speed	20 seconds	Movie
Hook Bounce	B&W Movie	20 seconds	Movie
* Speed Indicator	B&W Movie	20 seconds	Movie

* Speed indicator should show in the same coverage as the hook.

* Requires review of film.

ALL AMERICAN ENGINEERING COMPANY
WILMINGTON 99, DELAWARE

TEST PLAN

Project: Model 3500 Arresting Gear Tests Location of Test: NAFEC, Atlantic City, New Jersey

Test Plan Number: 1476-4 Test Date: Commence: 1 October 1962

Test Engineer: W. R. Schlegel Overtime Authorized: Yes

Sales Order Number: 1485-554 (720) 1485-553

Prepared by: W. R. Schlegel, W. C. Buckson Date: 15 August 1962

Approved by:

WJC Collins Date: 8/17/62
(Project Manager)

Mcwardh Date: 8/16/62
(Project Engineer)

WCB Date: 8/16/62
(Instrumentation)

J Rhody Date: 11-2-62
(FAA Project Manager)

Distribution:
WCollins (6)
WRSchlegel (2)
WJNissley (3)
WCBuckson (3)
FMHighley (2)

TEST OBJECTIVES:

Determine compatibility between the Model 3500 Arresting Gear and:
(1) Boeing 720 Aircraft
(2) C-131 Aircraft

DESCRIPTION OF TEST COMPONENTS: (Include serial numbers where applicable.)

(1) Model 3500 Arresting Gear
(2) Federal Aviation Agency Owned Boeing 720 Aircraft
(3) Federal Aviation Agency Owned C-131 Aircraft

TEST SEQUENCE OF EVENTS:

Event Number	Event Description		
	Convair C-131:		
	SPEED	WEIGHT	REMARKS
1.	80 knots	50,000 pounds	On-Center
2.	90 knots	50,000 pounds	On-Center
3.	95 knots	50,000 pounds	On-Center
4.	95 knots	50,000 pounds	On-Center
5.	75 knots	47,500 pounds	20 feet Off-Center
6.	85 knots	47,500 pounds	20 feet Off-Center
7.	90 knots	47,500 pounds	20 feet Off-Center
8.	60 knots	47,500 pounds	40 feet Off-Center
9.	75 knots	47,500 pounds	40 feet Off-Center
10.	90 knots	47,500 pounds	40 feet Off-Center

TEST SEQUENCE OF EVENTS

Event Number	Event Description Boeing 720-027: SPEED	AIRCRAFT WEIGHT	ENGAGING POSITION
1	80 knots	135,000 lbs.	On-Center
2	95	135,000 lbs.	On-Center
3	110	135,000 lbs.	On-Center
4	125	135,000 lbs.	On-Center
5	130	135,000 lbs.	On-Center
6	80	135,000 lbs.	40 feet Off-Center
7	95	135,000 lbs.	40 feet Off-Center
8	110	135,000 lbs.	40 feet Off-Center
9	125	135,000 lbs.	40 feet Off-Center
10	65	220,000 lbs.	On-Center
11	80	220,000 lbs.	On-Center
12	95	220,000 lbs.	On-Center
13	110	220,000 lbs.	On-Center
14	125	220,000 lbs.	On-Center
15	130	220,000 lbs.	On-Center
16	65	220,000 lbs.	20 feet Off-Center
17	80	220,000 lbs.	20 feet Off-Center
18	95	220,000 lbs.	20 feet Off-Center
19	110	220,000 lbs.	20 feet Off-Center
20	125	220,000 lbs.	20 feet Off-Center
21	130	220,000 lbs.	20 feet Off-Center
22	80	220,000 lbs.	40 feet Off-Center
23	95	220,000 lbs.	40 feet Off-Center
24	110	220,000 lbs.	40 feet Off-Center
25	To be determined	220,000 lbs.	40 feet Off-Center
26	65	220,000 lbs.	60 feet Off-Center
27	80	220,000 lbs.	60 feet Off-Center
28	95	220,000 lbs.	60 feet Off-Center
29-30	Fly in and landing arrestments.		

PHOTOGRAPHIC REQUIREMENTS:

Subject	Type of Coverage	Time of Action	Presentation Form
*Deck Pendant during Engagement (only one half of entire pendant)	High Speed B&W	3 seconds	Movie
*Aircraft Hook during Engagement	Approximately 100 feet per second B&W	20 seconds	Movie
Aircraft and Gear	Sequence Pan B&W and Color Pan	20 seconds	Prints as requested
Hook Installation	Static Pan Color	N. A.	Movie
Gear Installation	Static Pan Color	N. A.	Movie
Faking Box	Static Pan and during Engagement Color	N. A.	Movie
Gear and Hook Installation, etc.	B&W Stills	N. A.	Contact Prints

* These items only required for each run.

* Requires review of film.

PARAMETERS TO BE MEASURED:

Parameter	Location	Accuracy Required	Resolution Required	Maximum Value Anticipated
Gear:				
T_1 and T_2 Cable Tension	See Figure 1	3%	500 pounds	150,000 pounds
V_1 and V_2 Cable Velocity	See Figure 1	1%	0.5 knots	130 knots
V_3 Aircraft Engaging Velocity	See Figure 1	1%	0.5 knots	130 knots
P_1 and P_2	See Figure 1	3%	20 psi	3,000 psi
Aircraft: (720)				
Strain				
S_7 and S_8	See Figure 2	3%	100 Mi/I	Unknown
S_{10} through S_{19}	See Figure 2	3%	100 Mi/I	Unknown
S_{21} and S_{23}	See Figure 2	3%	100 Mi/I	Unknown
S_{29} through S_{34}	See Figure 2	3%	100 Mi/I	Unknown
Hook Rotation	At Rotation Point of Hook	3%	0.5 deg.	$\pm$ 25 degrees
Hook Load	Strain Gages on Hook	2%	500 pounds	185,000 pounds
A_1 Aircraft Fore and Aft "g"	Station 670	3%	0.1 "g"	1.0 "g"
A_2 Aircraft Lateral "g"	Station 1406	3%	0.1 "g"	1.0 "g"
A_3 Engine Lateral "g"	Engine #1	3%	0.1 "g"	1.0 "g"
A_4 Engine Fore and Aft "g"	Engine #1	3%	0.1 "g"	1.0 "g"
Nose Gear Vertical Position	Nose Gear Strut	3%	0.5 inch	
Aircraft: (C-131)				
Hook Load	On Hook	3%	150 pounds	55,000 pounds
Hook Rotation	At Rotation Point of Hook	3%	0.5 deg.	$\pm$ 25 degrees
Fore and Aft "g"	C.G. of Aircraft	3%	0.1 "g"	$\bar{1}$.5 "g"

DATA REQUIREMENTS:

Final Data Due:______________________

Parameter	Data Specifications	Presentation Format	Plotted on Same Graph
Nose Gear Vertical Postion		Plotted versus Time and Submitted to Federal Aviation Agency	
Cable Tension	Port and Starboard; initial, dynamic, and hydraulic peaks	Tabulated versus Run	2
Hook Load	Initial, Dynamic, and Hydraulic Peaks	Tabulated versus Run	2
Aircraft Accelera-tion	Initial, Dynamic, and Hydraulic Peaks	Tabulated versus Run	2
Aircraft Weight		Tabulated versus Run	2
Runout		Tabulated versus Run	2
Aircraft Engaging Velocity		Tabulated versus Run	2
Hook Rotation	Degrees from Centerline	Plotted versus Time	3
Off-Center Distance		Tabulated versus Run and Noted on Plot 3	2
Strain	Significant Load Paths as Noted from Test	Plotted versus Hook Load	4
		* Requires review of traces.	

BY ________ DATE ________ SUBJECT ________________ SHEET NO. ______ OF ______
CHKD. BY ______ DATE ________ JOB NO. ____________

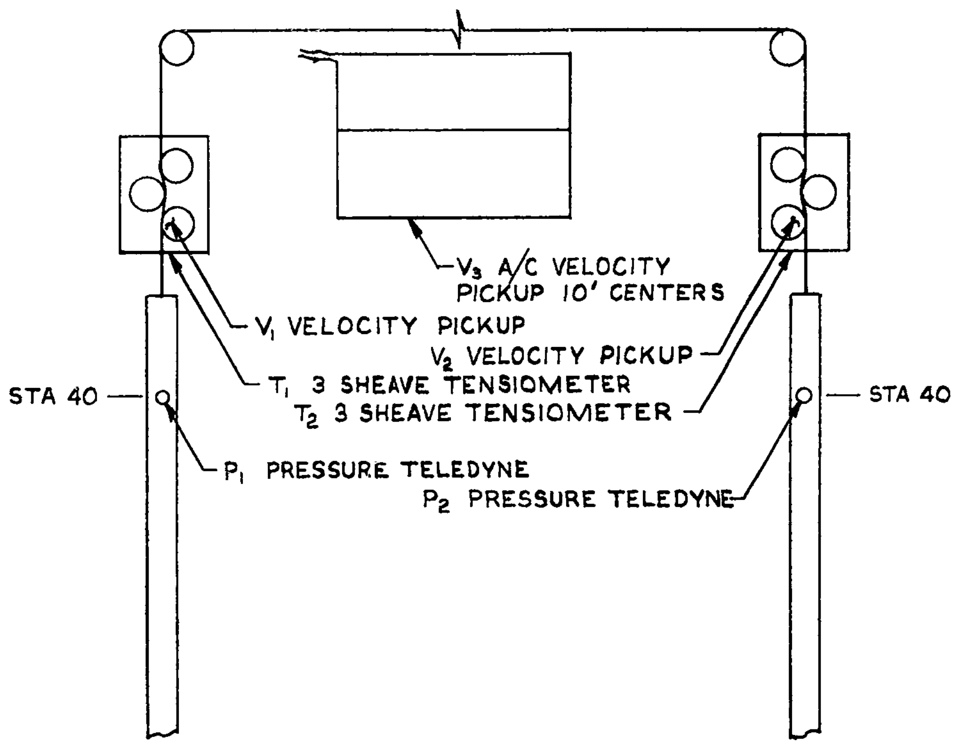


FIGURE 1. TRANSDUCER LOCATIONS

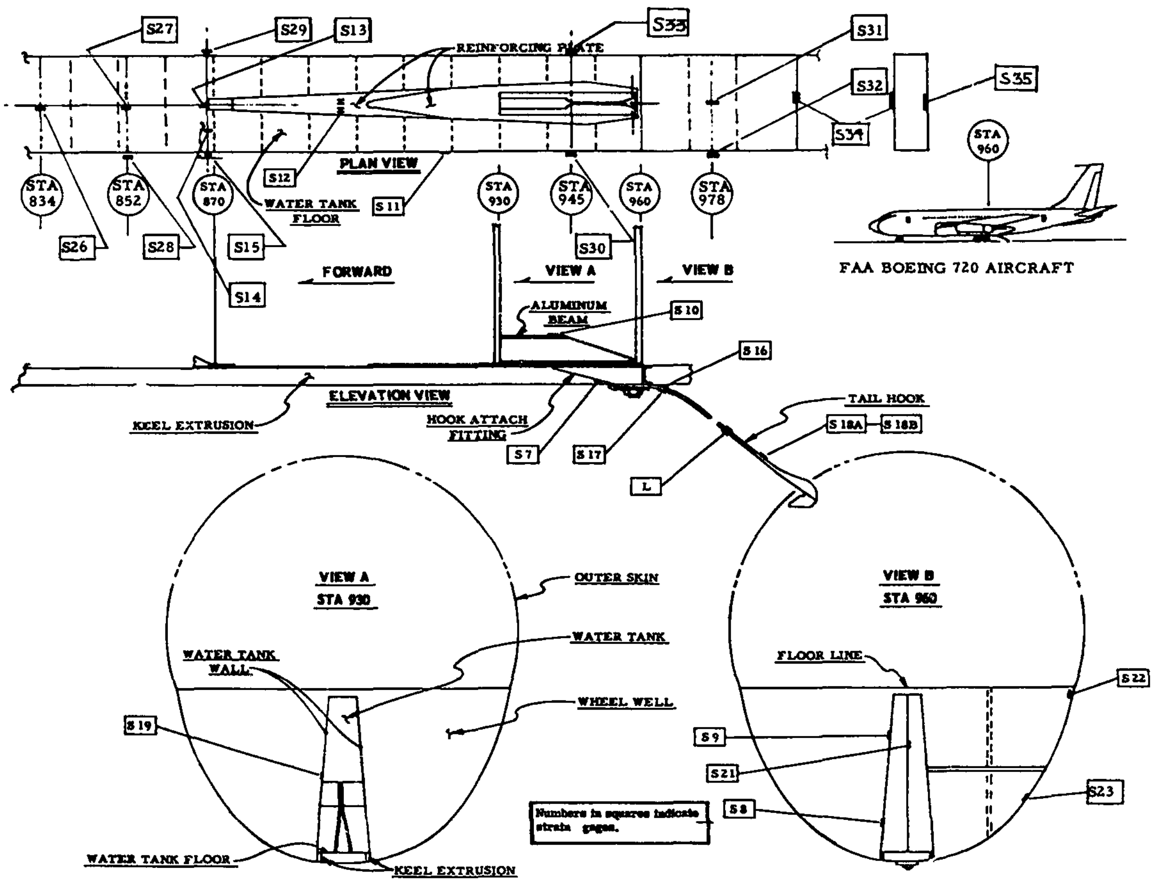


Figure 2 Strain Gage Locations

MODEL 3500 A/G TESTS AT NAFEC, ATLANTIC CITY, NEW JERSEY

Form E-138

ALL AMERICAN ENGINEERING COMPANY
WILMINGTON 99, DELAWARE

TEST PLAN

Project: Model 3500 Arresting Gear   Location of Test: Georgetown, Delaware

Test Plan Number: 1476-5   Test Date: ____________

Test Engineer: W. R. Schlegel   Overtime Authorized: ____________

Sales Order Number: 1485-441

Prepared by: W. C. Buckson/E. Carvalho   Date: 3 October 1962

Approved by: Distribution:

W. C. Collins
(Project Manager)   Date: ______

W. R. Schlegel
(Project Engineer)   Date: 10/6/62

W. C. Buckson
(Instrumentation)   Date: 10/4/62

Chody
(FAA Project Manager)   Date: 10-30-62

TEST OBJECTIVES:

To determine runway impact effects on All American Engineering Company Designed 720 and 707 hook points

DESCRIPTION OF TEST COMPONENTS: (Include serial numbers where applicable.)

1. Dead Load 113
2. All American Engineering Company's 720 tail hook and point

TEST SEQUENCE OF EVENTS

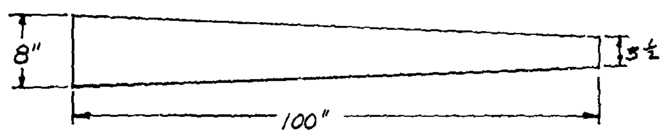
Event Number	Event Description
1 through 25	Install All American Engineering Company 720 hook shank and point on Dead Load 113 on the hard point designed for hook bounce tests. Raise the hook point to 77 inches above ground level. Release the hook.

PHOTOGRAPHIC REQUIREMENTS:

Subject	Type of Coverage	Time of Action	Presentation Form
Test Installation	Still - B&W	-----------------	Prints
			* Requires review of film.

BY CC	DATE 10-3-62	SUBJECT HOOK HEIGHT CALCULATIONS	SHEET NO. 1 OF 3
CHKD. BY	DATE		JOB NO.

GIVEN A FLAT TAPERED SPRING WITH EFFECTIVE DIMENSIONS AS INDICATED IN (FIG.1) HAVING A THICKNESS OF $\frac{1}{2}$ IN.



(FIG.1)

MEASURED SHANK WEIGHT = 118 LB
HOOK POINT FITTING + HOOK POINT WEIGHT = 21+12 = 33 LB

THE EFFECTIVE WEIGHT OF THE HOOK ASSEMBLY, W_E, IS;

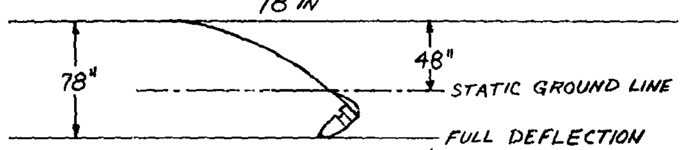
$$W_E = 33 + (.23)118 = 60.2 \text{ LB}$$

WHERE .23 IS THE SHANK EFFECTIVE WGT. FACTOR

SPRING CONSTANT $K = P/\delta$

WHERE P IS APPLIED LOAD
δ IS SPRING DEFLECTION

$$\text{MEASURED } K = \frac{368 \text{ LB}}{78 \text{ IN}} = 4.59 \frac{\text{LB}}{\text{IN}}$$



(FIG.2)

LET S = SPRING DEFLECTION

FORCE EXERTED AT FULL DEFLECTION = $KS = 4.59 \times 78 = 358$ LB
" " " STATIC GROUND LINE = $KS = 4.59 \times 48 = 220$ LB

THE FREE END VELOCITY FOR A FLAT SPRING WITH A GIVEN DEFLECTION;

(1) $$V = \sqrt{2A\frac{S}{12}}$$

A, THE TOTAL ACCELERATION ACTING ON THE FREE END;

(2) $$A = \frac{F(32.2)}{2\,W_E} + 32.2$$

(3) $$F = KS$$

SOLVING FOR EQUN (1) BY SUBSTITUTING (2) + (3)

(4) $$V = \sqrt{0.0446\,KS^2 + 5.35\,S}$$

WITH $K = 4.59$ #/IN
$S = 78$ IN

$$V = \sqrt{0.0446(4.59)(78)^2 + 5.35(78)}$$

$$V = \sqrt{1662}$$

$$V = 40.8 \text{ F.P.S.}$$

WITH A MAXIMUM AIRCRAFT DESCENT VELOCITY OF 10 F.P.S. THE TOTAL IMPACT VELOCITY OF THE HOOK POINT AT FULL DEFLECTION;

$$= 40.8 + 10 = 50.8 \text{ F.P.S.}$$

TO EFFECT THE MAXIMUM VELOCITY CALCULATED ABOVE AT THE STATIC GROUND LINE, IT IS NECESSARY TO DETIRMINE THE ADDITIONAL SPRING DEFLECTION

$$V = \sqrt{2A\left(\frac{S-30}{12}\right)} \qquad (5)$$

WHERE $(S-30)$ INDICATES DIFFERENCE BETWEEN STATIC GROUND LINE + FULL DEFLECTION

$$A = \frac{(30K+F)}{2W_E}32.2 + 32.2 \qquad (6)$$

COMBINING + SOLVING FOR V

$$V = \sqrt{(S-30)(0.0446\,K[S+30] + 5.35)}$$

GIVEN $V = 50.8$
$K = 4.59$

$$50.8 = \sqrt{(S-30)(0.0446 \times 4.59[S+30] + 5.35)}$$

$$0.205S^2 + 5.35S - 2925 = 0$$

$$S = 107 \text{ IN}$$

OVERBEND $= 107 - 78 = 29$ IN

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